TA 7417- IND: Support for the National Action Plan on Climate Change

Support to the National Water Mission

Final Report September 2011
Appendix 2 Lower Sutlej Sub Basin

PREPARED FOR
Government of India
Governments of Punjab, Madhya Pradesh and Tamil Nadu
Asian Development Bank

Appendix 2

Lower Sutlej Sub Basin Punjab

SUMMARY OF ABBREVIATIONS

A1B	IPCC Climate Change Scenario A1 assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B).
A2	IPCC climate change Scenario A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change.
ADB	Asian Development Bank
AGTC	Agriculture Technocrats Action Committee of Punjab
AOGCM	Atmosphere Ocean Global Circulation Model
APHRODITE	Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources - a observed gridded rainfall dataset developed in Japan
APN	Asian Pacific Network for Global Change Research
AR	Artificial Recharge
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
AWM	Adaptive Water Management
B1	IPCC climate change Scenario B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy.
B2	IPCC climate change Scenario B2 describes a world with intermediate population and economic growth, emphasising local solutions to economic, social, and environmental sustainability.
BBMB	Bhakra Beas Management Board
BCM	Billion Cubic Metres
BML	Bhakra Main Line Canal
BPL	Below the Poverty Line
BPMO	Basin Planning and Management Organisation of the CWC
BSL	Beas Sutlej Link
CAD	Command Area Development
CADA	Command Area Development Authority
CBO	Community Based Organisation
CCA	Command Control Area
CCIP	Climate Change Implementation Plan
CDM	Clean Development Mechanism
CDMR	Cauvery Delta Modernisation Report
CESER	Centre for Earth Systems Engineering Research, Newcastle University, UK
CGIAR	Consultative Group on International Agricultural Research
CGWA	Central Ground Water Authority
CGWB	Central Ground Water Board
CMIP	Coupled Model Intercomparison Project - an IPCC initiative to compare climate models
CMR	Cauvery Modernization Report
CNES	French Centre National d'Etudes Spatiales
CPCB	Central Pollution Control Board
CSK HPAU	CSK Himachal Pradesh Agricultural University
cusecs	cubic feet per second
CWC	Central Water Commission
CWPRS	Central Water and Power Research Station
DEA	Department of Economic Affairs
DEM	Digital Elevation Model
DJF	December-January-February
DMC	Developing Member Country
DMR	Delta Management Report
DSS	Decision Support System
DSSAT	Decision Support System for Agricultural Technology
DTR	Diurnal Temperature Range
EC	Electrical Conductivity
ED&MM	Exploratory Drilling and Materials Management
EIA	Environmental Impact Assessment
EMC	Environmental Monitoring Committee
EMP	Environmental Management Plan
ESSP	Earth System Science Programme
ETo	Evapotranspiration

FAO	Food and Agriculture Organisation of the United Nations
FASS	Farmers Advisory Services Schemes
FPARP	Farmer's Participatory Action Research Programme
FYP	Five Year Plan
GCM	Global Circulation or Climate Model
GIS	Geographic Information Systems
GLOF	Glacial Lake Outburst Flood
GOI	Government of India
GRBMP	Ganga River Basin Management Plan
GSI	Geological Survey of India
GW	Groundwater
HAM	Hectare Metres
HIS	Hydrological Information System
HP	Himachal Pradesh
HP2	Hydrology Project 2
I&D	Irrigation and Drainage
ICIMOD	International Centre for Integrated Mountain Development
ICT	Information and Communication Technologies
IITM	Indian Institute for Tropical Meteorology
IMD	Indian Meteorological Department
IMTI	Irrigation Management Training Institute
INCCA	Indian Network of Climate Change Assessment
IPCC	International Panel on Climate Change
IRBM	Integrated River Basin Management
IS	Institutional Strengthening
ISRO	Indian Space Research Organisation
IWRM	Integrated Water Resources Management
JF	January-February
JJAS	June-July-August-September
KVK	Krishi Vigyan Kendras
LBC	Lateral Boundary Conditions
l/s/ha	litre per second per hectare
LBC	Lateral Boundary Conditions
LIS	Legal Information System
MAM	March-April-May
MCM	Million Cubic Meters
MODFLOW	Three-dimensional finite-difference groundwater flow model developed by the US Geological Survey
MoEF	Ministry of Environment and Forests
MOHC	Met Office Hadley Centre (UK)
MOU	Memorandum of Understanding
MoWR	Ministry of Water Resources
MP	Madhya Pradesh
msl	Mean Sea Level
MSP	Minimum Support Price
MTM	Megha-Tropiques Mission
NAPCC	National Action Plan for Climate Change
NARBO	Network of Asian River Basin Organisations
NCDS	National Committee on Dam Safety
NCIWRD	National Commission for Water Resources Development
NCMRFF	National Centre for Medium Range Weather Forecasting
NDC	National Data Centre, India
NDMA	National Disaster Management Agency
NGO	Non-Governmental Organisation
NIH	National Institute of Hydrology
NMSKCC	National Mission on Strategic Knowledge for Climate Change
NREGA	National Rural Employment Guarantee Act
NRSA	National Remote Sensing Agency
NSRC	National Remote Sensing Centre
NWH	North-western Himalayan Region
NWM	National Water Mission of the NAPCC
ON	October-November
OND	October-November-December
PAFC	Punjab Agro Foods Corporation
PAO	Project Appraisal Organisation

PATA	Policy Advisory Technical Assistance
PAU	Punjab Agricultural University
PES	Payment for Environmental Services
PIM	Participatory Irrigation Management
PPE	Perturbed Physics Ensemble
PPP	Public Private Partnerships
PRA	Participatory Rural Appraisal
PRECIS	Providing Regional Climates for Impacts Studies
PRI	Panchayati Raj Institutions
PWD	Public Works Department
Q14, Q1 Q0	Identifiers for runs with different perturbations
QUMP	Quantifying Uncertainty in Model Predictions is an approach which aims to provide probabilistic projections of future climate.
RegCM	Regional Climate Model system RegCM , originally developed at the National Center for Atmospheric Research (NCAR), is maintained in the Earth System Physics (ESP) section of the International Centre for Theoretical Physics (ICTP), Trieste
R&R	Rehabilitation and Resettlement
RBO	River Basin Organisation
RCM	Regional Circulation or Climate Model
RCP	Representative Concentration Pathways
RGNGT&RI	Rajiv Gandhi National Ground Water Training and Research Institute
RSC	Residual Sodium Carbonate
RTDSS	Real Time Data Support Systems
SAM	Survey Assessment and Monitoring
SAPCC	State Action Plans for Climate Change
SD&MA	Service Delivery and Management Alternatives
SGWA	State Ground Water Authority
SML	Sustainable Management and Liaison
S-NWM	ADB Support TA to the National Water Mission of the NAPCC
SRES	Special Report on Emission Scenario (IPCC SRES November 2000
SRI	System of Rice Intensification
SRTM90	A DEM with 90m resolution developed by the Shuttle Radar Topography Mission
START	Global change system for analysis, research and training coordinated by IIT Mumbai
SWAP	Soil-Water-Atmosphere-Plant
SWAT	Soil and Water Assessment Tool
T&TT	Training and Technology Transfer
TA	Technical Assistance
TERI	The Energy and Resources Institute
TN	Tamil Nadu
TNRRI	Tamil Nadu Rice Research Institute
TNSEB	Tamil Nadu State Electricity Board
UKIERI	UK India Education and Research Initiative
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
UT	Union Territory
WC	Conveyance efficiency
WD	Drainage efficiency
WEAP	Water Evaluation and Planning System- planning tool from Stockholm Environment Institute
WF	On-farm application efficiency
WHS	Water Harvesting Structures
WP	Water use efficiency at the project level
WQAA	Water Quality Assessment Authority
WR	Reservoir or weir efficiency
WRCRC	Water Resources Control and Review Council
WRD	Water Resources Department
WRIS	Water Resources Information System
WRO	Water Resources Organisation
WUA	Water Users Association
WWF	World Wildlife Fund

TABLE OF CONTENTS

APPENDIX 2A SUB BASIN PROFILE

APPENDIX 2B STRATEGIC FRAMEWORK PLAN

FIGURES and TABLES

Appendix 2A Lower Sutlej Sub Basin Punjab

Sub Basin Profile

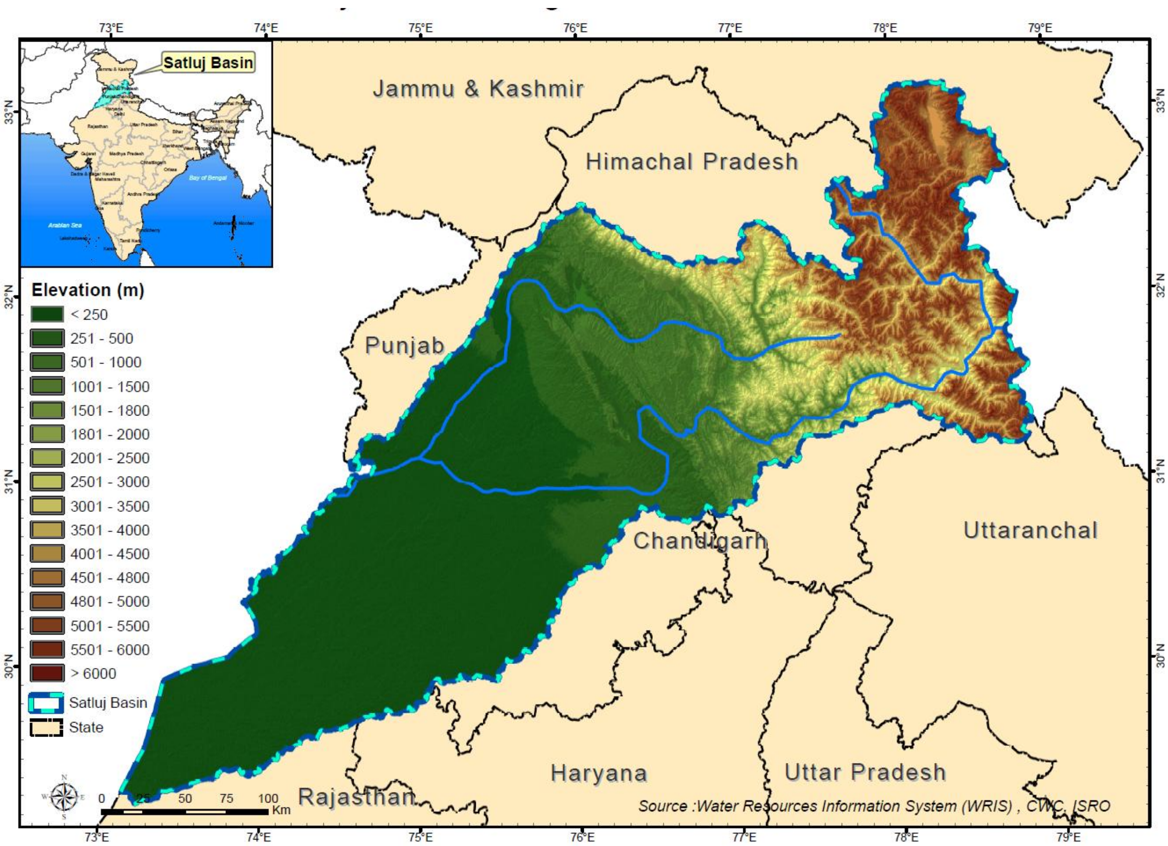
APPENDIX 2A LOWER SUTLEJ SUB BASIN PROFILE

I. SURFACE WATER RESOURCES

A. Sutlej Basin Characteristics

1. The Sutlej River is one of the main tributaries of the Indus River System and is located in the western Himalayan Region. The basin location and key topographic and drainage details are shown in Figure 1

Figure 1 Digital Elevation Model



2. The Sutlej River originates from the lakes of Mansarover and Rakastal in the Tibetan plateau at an elevation of more than 4,500 m. The Sutlej River enters India near Shipkila at an elevation of about 2530 m and continues to flow in Himachal Pradesh through Wangtoo and Kian before reaching Bhakara reservoir. The total drainage area of the Sutlej River up to Bhakra Reservoir is about 56,000 km2. The major part of the basin (35,725 km2) lies in the Tibetan plateau experiences little precipitation and has cold desert type of climate. The principal tributary of Sutlej River, known as Spiti, joins the Sutlej River just after entering India and contributes about two thirds of the total flow at Khab (the confluence of the Sutlej and Spiti).

3. Bhakra Dam was completed in 1963, and is one of the highest gravity dams in the world at 226 m. Bhakra reservoir has a gross storage capacity of 9,800 Mm^3, and a live storage of 7,400 Mm^3, which is about 43% of the mean annual inflow of 16,000 Mm^3. A diversion from the River Beas at Pandoh (Beas Sutlej Link, BSL) augments inflows to Bhakra reservoir and provides about 25% of the inflow to Bhakra reservoir. There is a hydropower station on the BSL at Dehar, and this has an installed capacity of 990 MW. Bahkra and Pong reservoirs are operated by the Bhakra Beas Management Board (BBMB).

4. Bhakra reservoir provides potable water supply for Chandigarh and Delhi, and irrigation water for an area of some 242,800 ha, with supplies to Punjab, Haryana and Rajasthan. The two power houses at Bhakra have a total installed capacity of 1,325 MW. About 13 km downstream of Bhakra is Nangal Dam. Nangal dam is used to re-regulate releases from Bhakra reservoir which are used for peak power generation. Two canals offtake from Nangal dam leading to two further hydropower plants about 33 km downstream, each of which has an installed capacity of 77 MW. Downstream of these plants some water is returned to the river, and some diverted to the Bhakra Main Line Canal (BML). The BML is 164 km long, and provides irrigation water supply for the States of Punjab, Haryana and Rajasthan, and potable water supply for Chandigarh and Delhi. The BML has a capacity of 350 m3/s (12,455 ft3/s).

5. Significant hydropower potential exists upstream of Bhakra. Run of river hydropower projects have been developed at Nathpa Jhakri (1,500 MW) and Baspa (300 MW).. A number of new hydropower projects like Karcham-Wangtoo (1000 MW), Rampur (400 MW), Kol (800 MW) are under construction and several others are under investigation There are plans for further hydropower development including a high storage dam at Khab. A summary of the status of hydropower production is given in Table 1.

Table 1 Status of Hydropower in the Sutlej

Status	MW	%
Operational	1,649	17
Under Construction	4,571	47
Under Investigation	2,335	24
Pending Investigation	1,090	11
No information	55	1
Total	9700	100

6. Most of the run of river projects divert water through tunnels running along the valley sides to discharge to a power station some distance downstream of the diversion. At diversion sites there may be a few hours of storage that permits the stations to be used for peaking.

7. The Indian part of Sutlej basin upstream of Bhakra dam is about 20,275 km^2. The Sutlej river is the longest and largest river in the Himachal Pradesh. The elevation of the upper basin varies from about 500 m at Bhakra dam to 7000 m. However, only very small area exists above 6000 m. The mean elevation of the basin is about 3600 m. Although, the basin covers outer, middle and greater Himalayan ranges, the major part of basin lies in the greater Himalayan ranges. Owing to large differences in the relief, the basin is characterized by the diversified climatic patterns. Westerly weather disturbances produce most of the precipitation during winter in the middle and upper parts of the upper basin. Winter precipitation in the upper basin falls mostly as snow. The mean annual rainfall (excluding snow) in the outer, middle and outer Himalayan ranges of the basin is about 1300, 700 and 200 mm, respectively (Singh and Kumar, 1997). The distribution of rainfall indicates that the rainfall is mostly concentrated in the lower part of the basin and has little influence in the greater Himalayan range. The snowline is highly variable, descending to an elevation of about 2000 m during winter and retreats to above 4500 m after the ablation period. About 65% of the upper basin area is covered with snow during winters (Singh and Jain, 2002). The Bhakra Beas Management Board (BBMB) is responsible for collection of hydrometeorological data (snowfall, rainfall, temperature, discharge) for the Sutlej and Beas basins.

8. The existing network of hydro meteorological stations in the upper Sutlej basin is very sparse. It is, however, being significantly improved under the Hydrology Project 2 (HP2). Under HP2 100 telemetered meteorological stations are being installed in the Upper Beas and Sutlej catchments. IMD are understood to be installing a further 80 telemetered stations. These stations will use a geostationary satellite for data transmission. The main purpose is for real time flood forecasting and operation of the Pong and Bhakra reservoirs.

9. In the last decade catastrophic flood events in the Sutlej basin due to cloud burst events and glacial lake outburst flood (GLOF) has resulted in many deaths, as well as destruction of houses, bridges, fields, forests and roads. Cloud burst event in Sutlej river occurred on 31 July-1 August, 2000 increased the water level in the Sutlej by 15 m in a short span of 6 hours. Discharge records in the Sutlej River at Rampur rose from 1530 to 5100 m^3/s in 2.5 hours, whereas at Suni (d/s of Rampur) discharge rose from 1830 to 6100 m^3/s in 2 hours. There was a widespread damage to life and property in Kinnaur district. About 100 people were killed during this flood event. Further, during summer 2004, a rockslide/landslide on the Pareechu river (Tibet), which joins the Spiti River in Himachal Pradesh (a tributary of the Sutlej

River) blocked the river at Ali Prefecture of Tibet and water got headed up the lake. The blockage occurred about 35 km from the India-China border. The increased rainfall and water flow from the upper reaches substantially raised water levels downstream. Thousands of human and animal lives were under threat. The local administration evacuated about 4,000 people from 60 vulnerable villages in Mandi, Kullu, Shimla, Kinnaur and Bilaspur districts. Nathpa Jhakri Hydroelectric Project (Rs 8500 crores, 1500 MW) which employs more than 1,000 people was closed due to expected flash flood. Fortunately the lake stabilized - inflow balanced with outflow. Since the debris wall was situated in a gorge, the water pressure from the swelling lake was absorbed by the mountain face on either side.

10. However, the glacial lakes at risk are located in remote and inaccessible area, but their bursting affects local communities in the downstream who are largely unaware of the event. ICIMOD in association with CSK Himachal Pradesh Agriculture University, Palampur University (H.P.), APN, START and UNEP has carried out inventory of glacial lakes and outburst floods for the Himachal Pradesh, which also includes Sutlej river (ICIMOD and others, 2004). This study shows that Sutlej river consists of 945 glaciers with a cumulative area of about 1218 km^2 and estimated ice reserve of about 95 km^3. There are 40 lakes in Sutlej basin with an area of about 137 km^2. Most of the lakes are small in size and about 35 lakes are found to be associated with glaciers. Three lakes in the Sutlej have been identified by ICIMOD to have risk of breach.

11. The main irrigation offtakes from the Sutlej River are at Ropar Barrage, about 60 km downstream of Nangal. Construction of Ropar Barrage was completed in 1882. Remodelling was carried out in the period 1952-54 in preparation for releases from Bhakara reservoir. Water is diverted from the right bank to the Bist Doab irrigation area and on the left bank to Sirhind command. The Sirhind canal has a capacity of 360 m^3/s. The Sutlej River basin downstream of Ropar Barrage is referred to in this report as the lower basin. The land is gently sloping in a south-westerly direction and is extensively developed for irrigated agriculture. In this part of the basin there is little runoff to the river system.

12. The Sutlej River is joined by the Beas River at Harike, where the Harike Barrage diverts water to the Rajasthan Canal and the Ferozepur. At Harike, inflows are also received from the Madhopur Beas link, which has a capacity of 280 m^3/s and brings water from the River Ravi. The barrage at Harike provides an important wetland habitat upstream. Downstream of the barrage there is no dry season flow. The Rajasthan Canal has a capacity of 520 m^3/s, and the Ferozpur Feeder a capacity of 315 m^3/s.

B. The Hydrometric Network

13. The hydrometric network in the basin upstream of Bhakra reservoir is operated by the BBMB. Currently they have 4 snow observatories, 17 snow gauge stations, 13 rain gauges, 9 stream gauging stations, 6 evaporation stations and one meteorological station in the upper Sutlej. As indicated above, the network is about to be significantly extended under HP2. The network of IMD meteorological stations in the lower basin is shown in Figure 2. This coverage would be considered reasonable for most planning purposes. IMD maintains a comprehensive register of its precipitation and meteorological stations.

14. The stations upstream of Bhakra Reservoir are important on a number of counts. They can be used to assess any historic trends that might be the result of climate change, and of course they are central to assessment of the surface water resources of the basin. These stations will also be used in the calibration of the SWAT model that will be used to assess potential future climate change impacts in the basin. Data for 34 gauge discharge stations, one Reservoir Level, 2 pond levels, 3 storage /releases have been provided for the period 1 Jan 1990 – 31 Aug 2010.

Figure 2 Location of Meteorological Measurement Stations

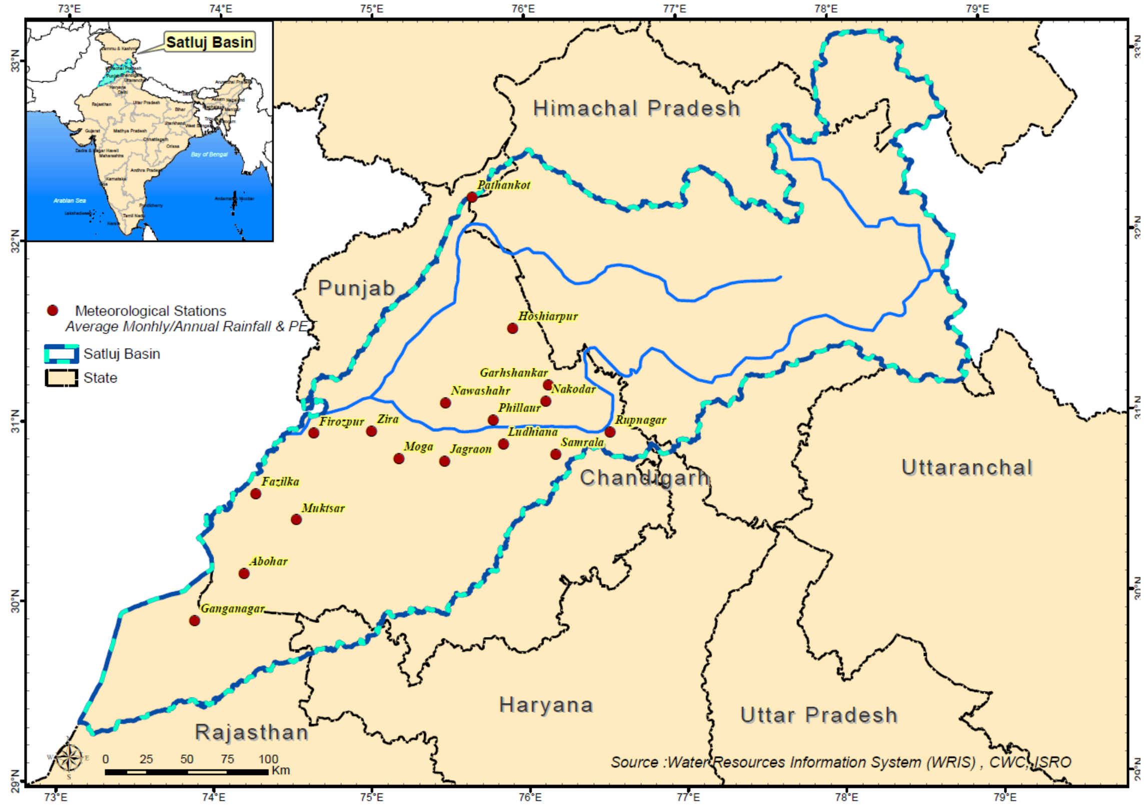
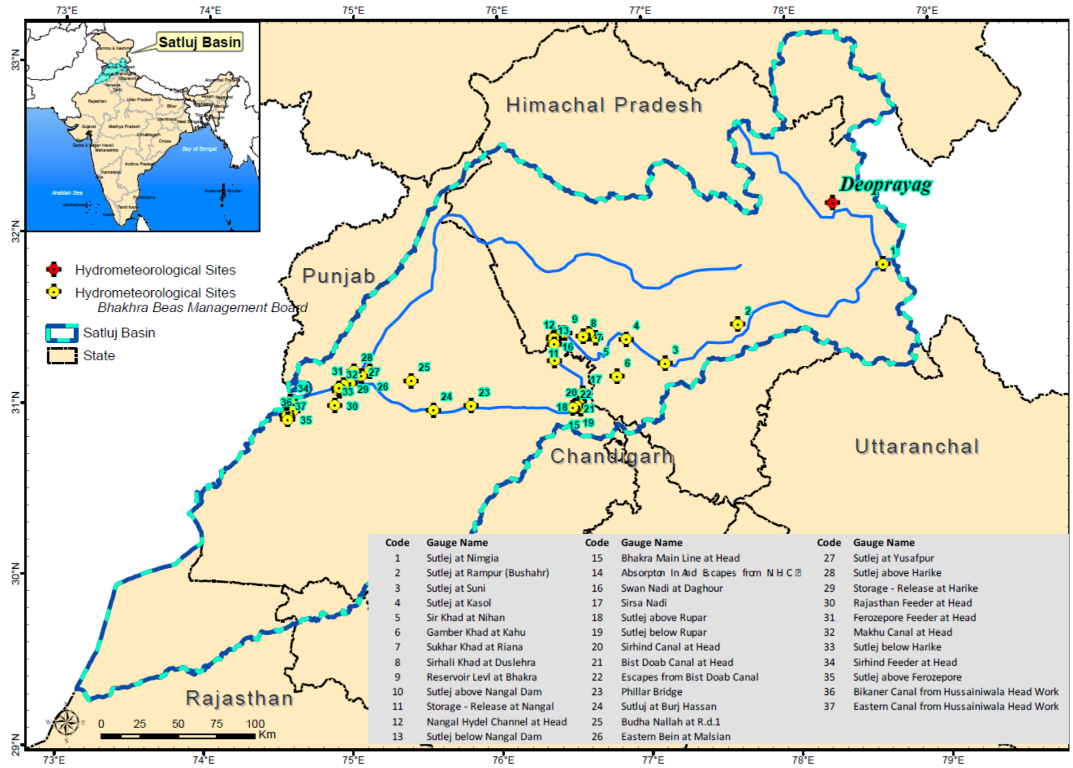


Figure 3 Hydrometeorological Sites



Code	Gauge Name	Code	Gauge Name	Code	Gauge Name
1	Sutlej at Nimgia	15	Bhakra Main Line at Head	27	Sutlej at Yusafpur
2	Sutlej at Rampur (Bushahr)	14	Absorpton In And Escapes from N H C	28	Sutlej above Harike
3	Sutlej at Suni	16	Swan Nadi at Daghour	29	Storage - Release at Harike
4	Sutlej at Kasol	17	Sirsa Nadi	30	Rajasthan Feeder at Head
5	Sir Khad at Nihan	18	Sutlej above Rupar	31	Ferozepore Feeder at Head
6	Gamber Khad at Kahu	19	Sutlej below Rupar	32	Makhu Canal at Head
7	Sukhar Khad at Riana	20	Sirhind Canal at Head	33	Sutlej below Harike
8	Sirhali Khad at Duslehra	21	Bist Doab Canal at Head	34	Sirhind Feeder at Head
9	Reservoir Levl at Bhakra	22	Escapes from Bist Doab Canal	35	Sutlej above Ferozepore
10	Sutlej above Nangal Dam	23	Phillar Bridge	36	Bikaner Canal from Hussainiwala Head Work
11	Storage - Release at Nangal	24	Sutluj at Burj Hassan	37	Eastern Canal from Hussainiwala Head Work
12	Nangal Hydel Channel at Head	25	Budha Nallah at R.d.1		
13	Sutlej below Nangal Dam	26	Eastern Bein at Malsian		

15. An assessment has been made of climatic norms in the lower Sutlej Basin for stations at Ludhiana and Ganganagr. The locations of these stations are shown in Figure 3. Ludhiana is in the north of the Sirhind irrigation command area while Ganganagr is in the extreme southwest of the command area. Original meteorological data could not be obtained from the Indian Meteorological Department (IMD) in time for the preparation of this report. Use was therefore made of the FAO CLIMWAT database[1] which includes mean monthly meteorological data for over 5000 stations worldwide.

16. Figure 4 shows climatic norms for Ludhiana, and includes potential evapotranspiration and effective rainfall calculated using the FAO CROPWAT 8 package[2]. CROPWAT 8 uses the FAO Penman method in the calculation of ETo, and calculates effective rainfall using the USDA S.C. method. It should be noted that precipitation is significantly skewed in the dry season months, and the use of mean monthly rainfall in estimating effective rainfall for irrigation water demands is probably not appropriate.

17. At Ludhiana, mean daily temperatures range from a low of about 13^oC in January to a high of about 33^oC in June. May and June are the hottest months with mean daily maximums close to 40^oC. The mean daily temperature range is typically about 12^oC. A maximum range of 15.5^oC occurs in May. The minimum range of about 8^oC occurs in July and August. Relative humidity is at its lowest in May, averaging 31%, and peaks in August at 76%. Wind speeds are generally in the range of 0.5 to 1.5 m/s, and are highest in May and June, when solar radiation is also at a its peak. The climatic parameters combine to give an annual potential evapotranspiration at Ludhiana of 1410 mm, with peak evapotranspiration in May and June. The peak daily rates of evapotranspiration occur in June with a mean of 6.8 mm/day. It is clear from Figure 4, that with the exception of the months of July and august, the is effective precipitation is far short of potential evapotranspiration. Mean annual rainfall at Ludhiana is 730 mm, and the computed mean annual effective rainfall is 570 mm.

18. The climatic norms at Ganganagar are shown in Figure 5, and follow a very similar pattern to those at Ludhiana. Mean daily temperatures are a few degrees higher at Ganganagar during the summer months, and the mean daily temperature range is higher than at Ludhiana, being 18^oC in April and 20^oC in November. Relative humidity at Ganganagar is lower than at Ludhiana, and wind speeds significantly higher. Solar radiation is marginally higher than at Ludhiana. The climatic norms to combine to produce potential evapotranspiration that is significantly higher than at Ludhiana. Annual potential evapotranspiration is estimated to be 1750 mm. Rainfall and effective rainfall at Ganganagar are 240 mm and 220 mm respectively. Irrigation demands in the southwest or tail end of the SirhinSirhind command will thus be significantly higher than those in the northeast.

C. Precipitation in the Basin

19. An analysis presented here is based on the IMD gridded 0.5^o×0.5^o data that covers the 35 year period 1971 to 2005.

1. Annual Precipitation

20. Figure 6 present isohyets of mean annual precipitation over the Basin. A distinct rainfall gradient exists as would be expected with the influence of the Himalayas in the north. In the lower basin and in the area of the Sirhind irrigation command, annual precipitation varies from about 250 mm in the southwest, to about 900 mm in the northeast near Ropar headworks. This clearly has implications for irrigation water allocations. In the upper basin, annual precipitation is in the range of 800 mm to 1300 mm. Precipitation is generally higher in the upper Beas than in the upper Sutlej.

[1] http://www.fao.org/nr/water/infores_databases_climwat.html

[2] http://www.fao.org/nr/water/infores_databases_cropwat.html

Figure 4 Climatic Norms at Ludhiana

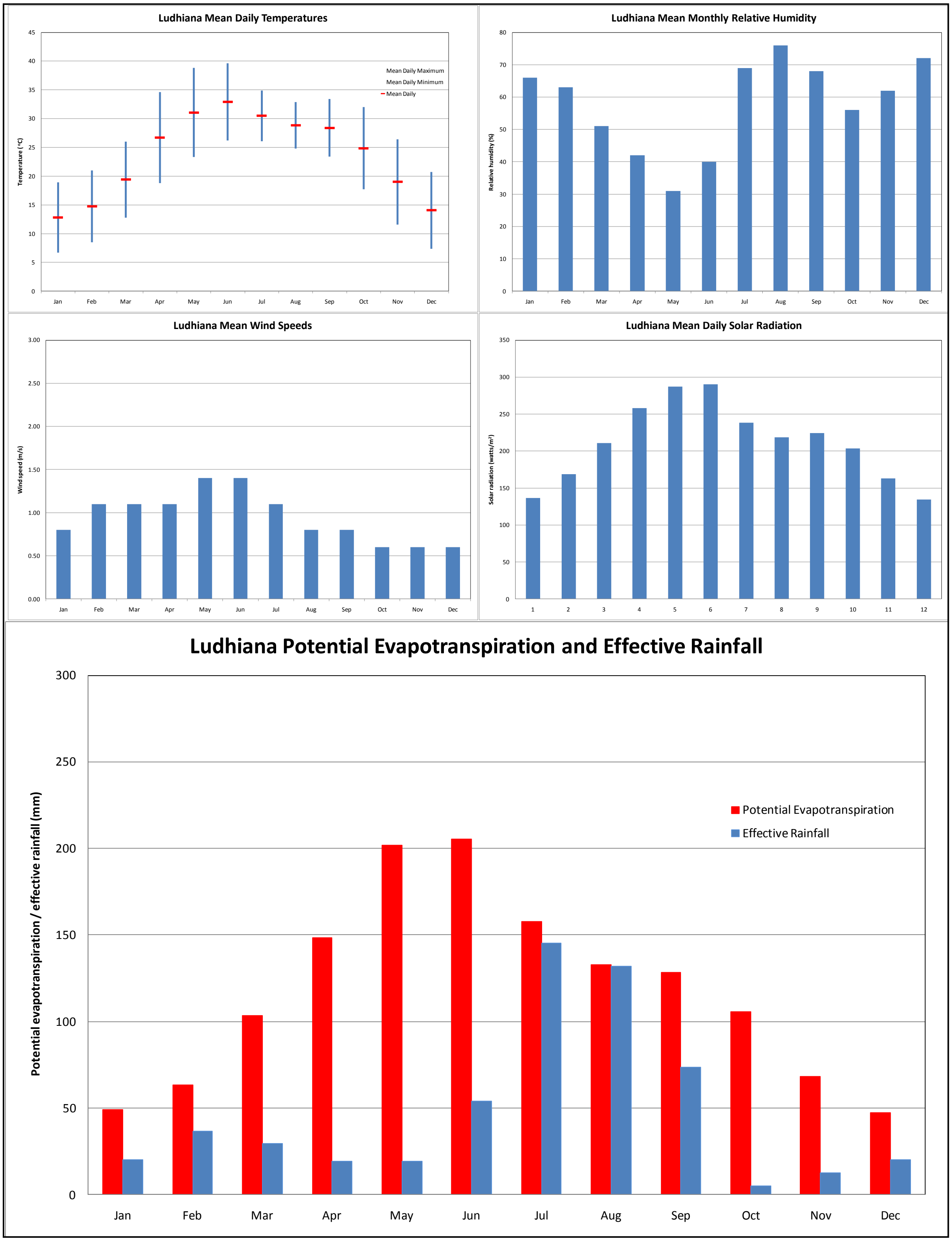


Figure 5 Climatic Norms at Ganganagr

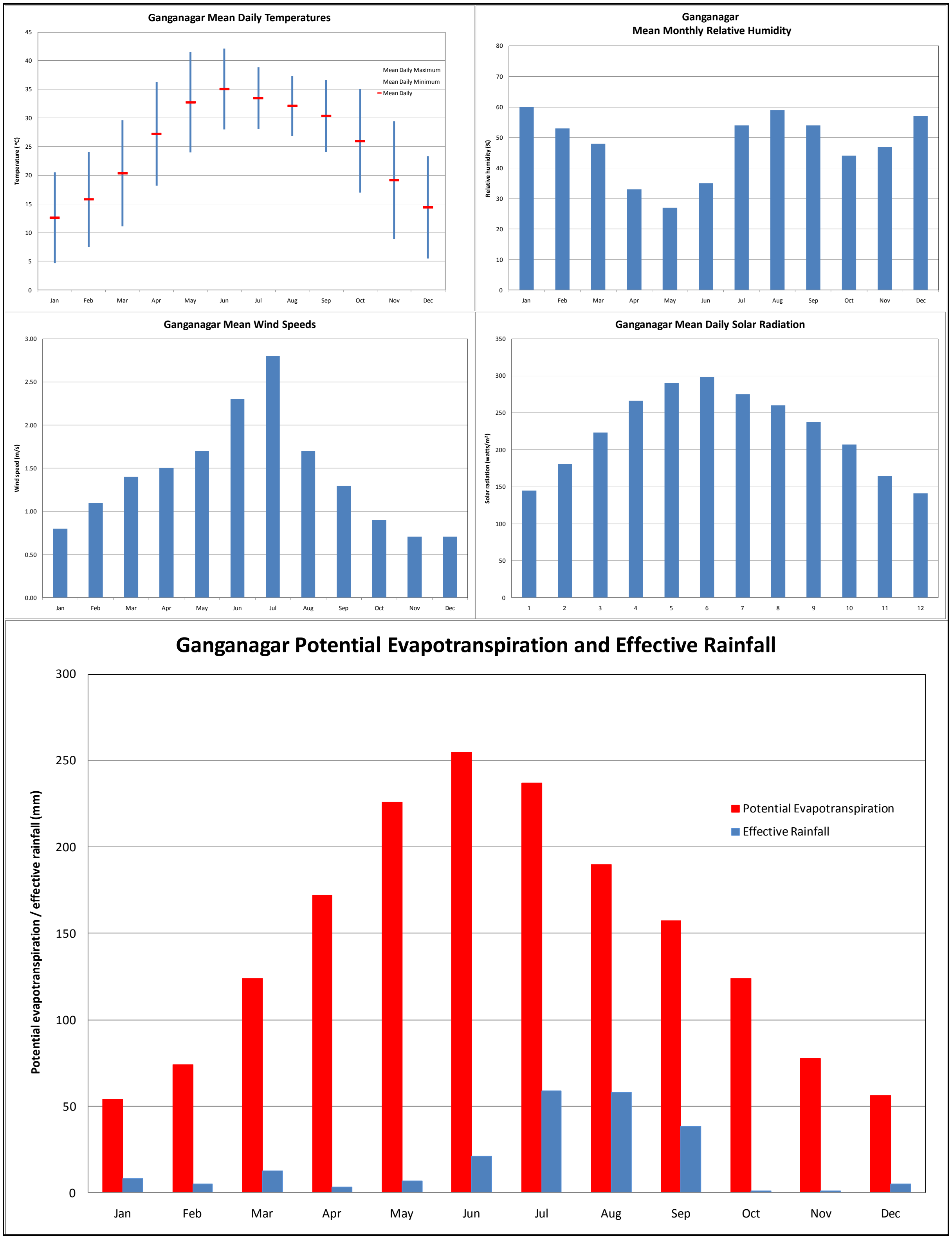
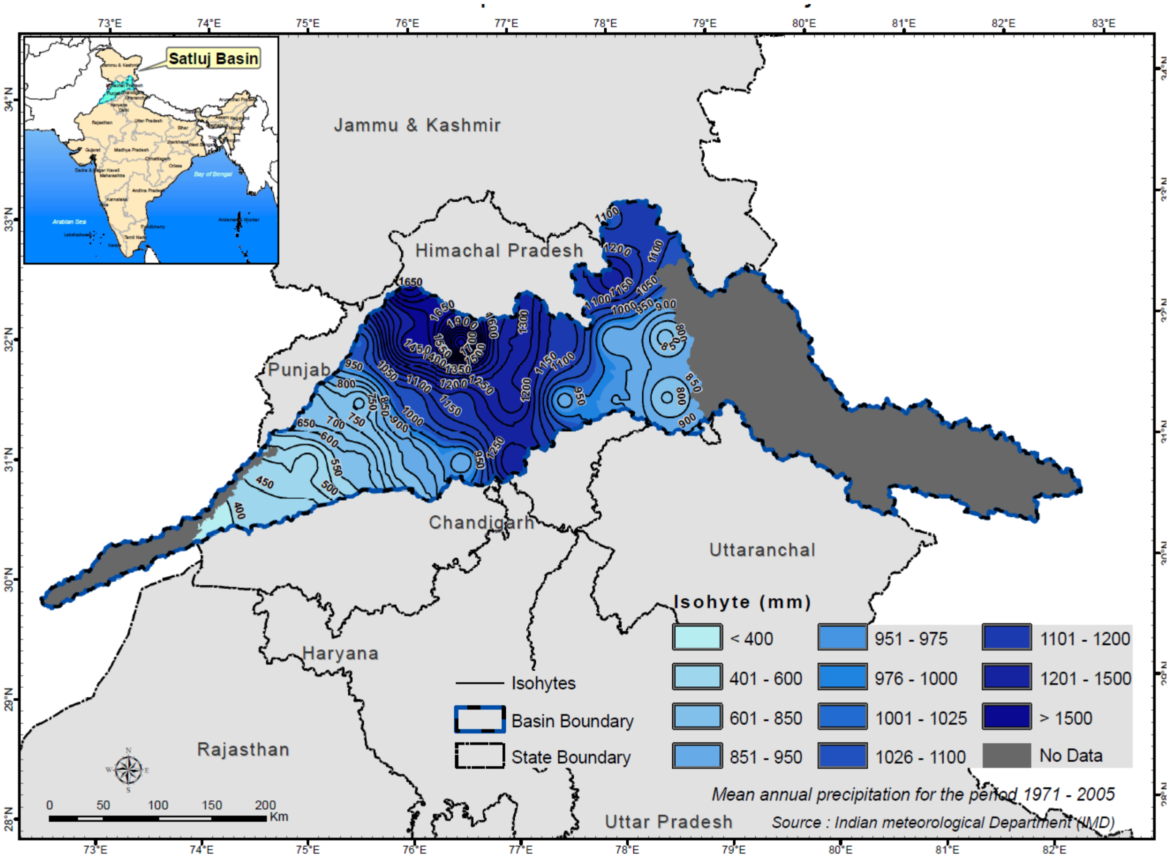


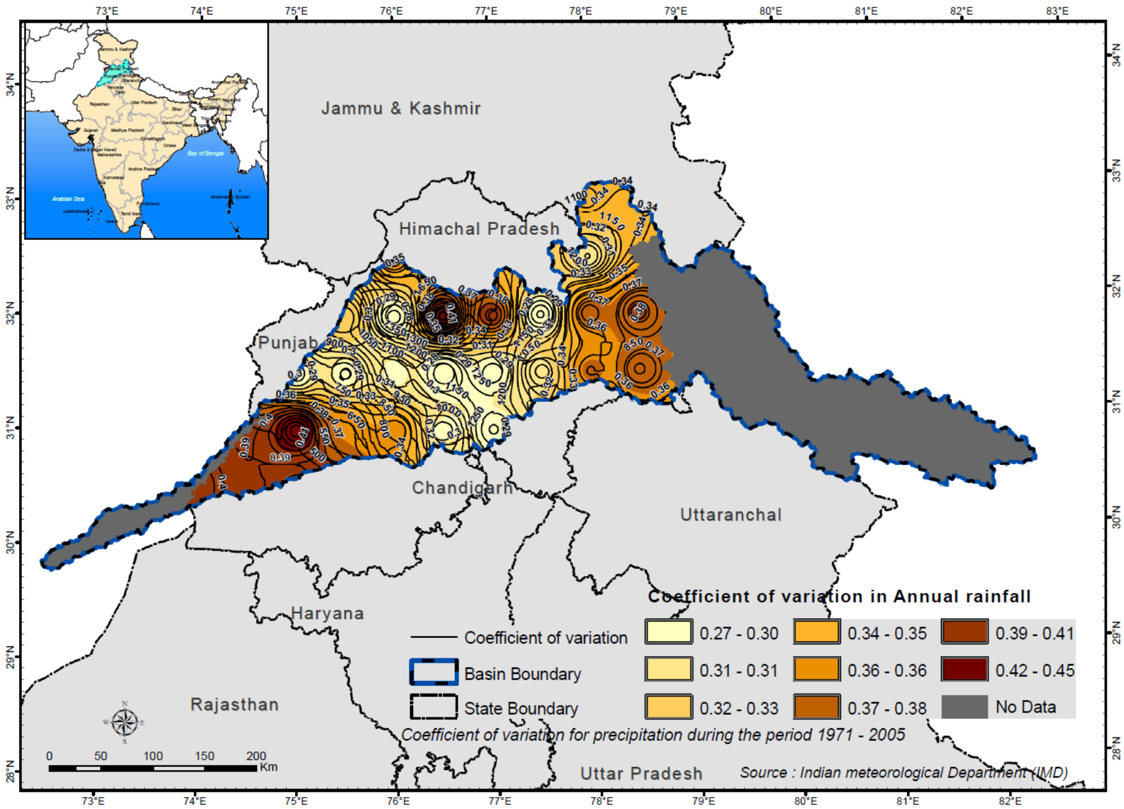
Figure 6 Mean Annual Precipitation



21. Coefficients of variation in annual rainfall are shown in Figure 7. Inter-annual variability tends to be highest in the southwest of the lower basin, and is lowest in the northeast of the lower basin around Ropar headworks. Variability then increases again into the upper basin. Inter-annual variability in rainfall is generally high. A feature of precipitation in the basin is that regional variability within any year can be high, with some parts receiving above average rainfall, while other parts receive below average rainfall. Figure 8 shows deviations from the mean of annual rainfall between 1971 and 2005, for each of the IMD grid squares in the Basin. Clearly some parts of the basin experience drought in the same years that other parts experience very wet conditions.

22. There is an indication from Figure 8 that conditions in the period 2000 to 2005 were generally below average, but there is no evidence of trend. Spatial variability has been explored further by separating out those grid squares representative of the lower basin. Basically the upper basin may be considered to provide the surface water resource available to the lower basin. In the lower basin precipitation is important in partly meeting crop water requirements.

Figure 7 Coefficient of Variation of Annual Rainfall



23. Figure 9 shows deviations from the mean of annual precipitation in the lower basin in the period 1971 to 2005 and Figure 10 deviations from the mean in the upper basin. Precipitation in the lower basin is clearly more variable in space and time than in the upper basin. There is a general tendency for similar cycles to be followed across the lower basin, but occurrence frequencies in an particular year are widely varied. In the upper basin there appears to have been much less spatial variability in the second part of the record (i.e. post 1989). The likelihood is that this may be the result of changes in the available precipitation data, possibly with a better observation network and hence more reliable areal estimation of precipitation after 1989. It has not as yet been possible to check with IMD if this is the case. It is also apparent that drought during the period 2000 to 2005 was more of an issue in the upper basin than in the lower basin.

Figure 8 Deviations from Mean of Annual Rainfall of all IMD Grids for Sutlej Basin

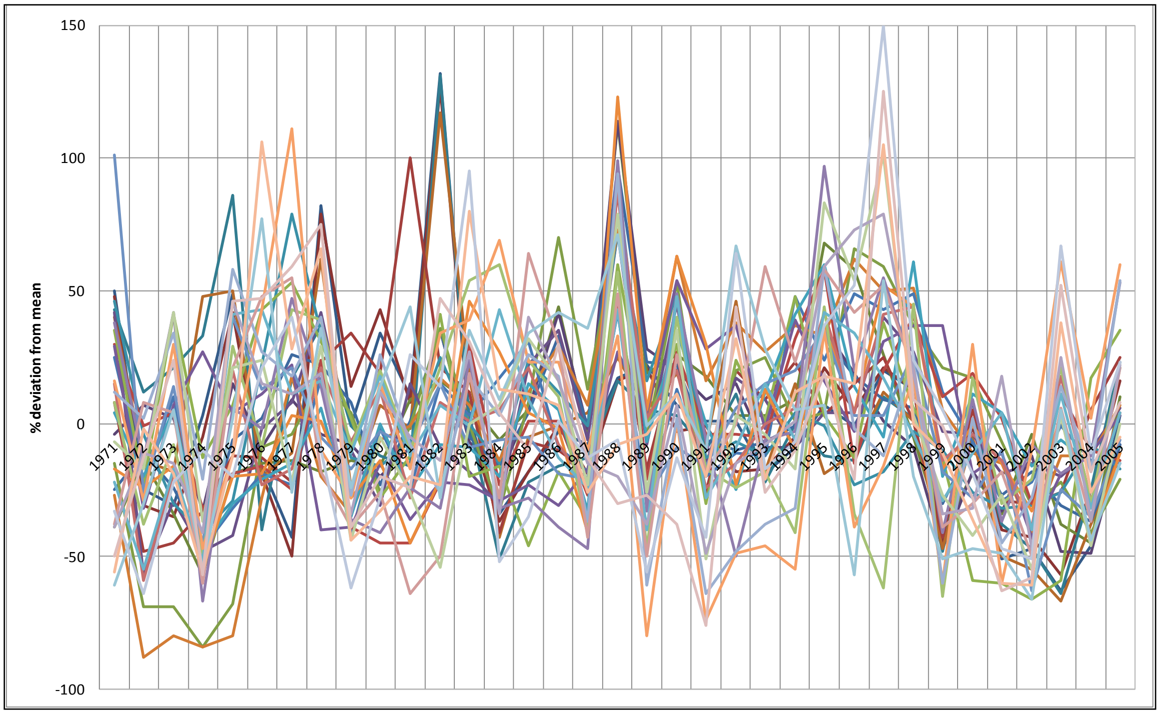


Figure 9 Deviations from the Mean of Annual Rainfall at all IMD grids in the Lower Sutlej Basin

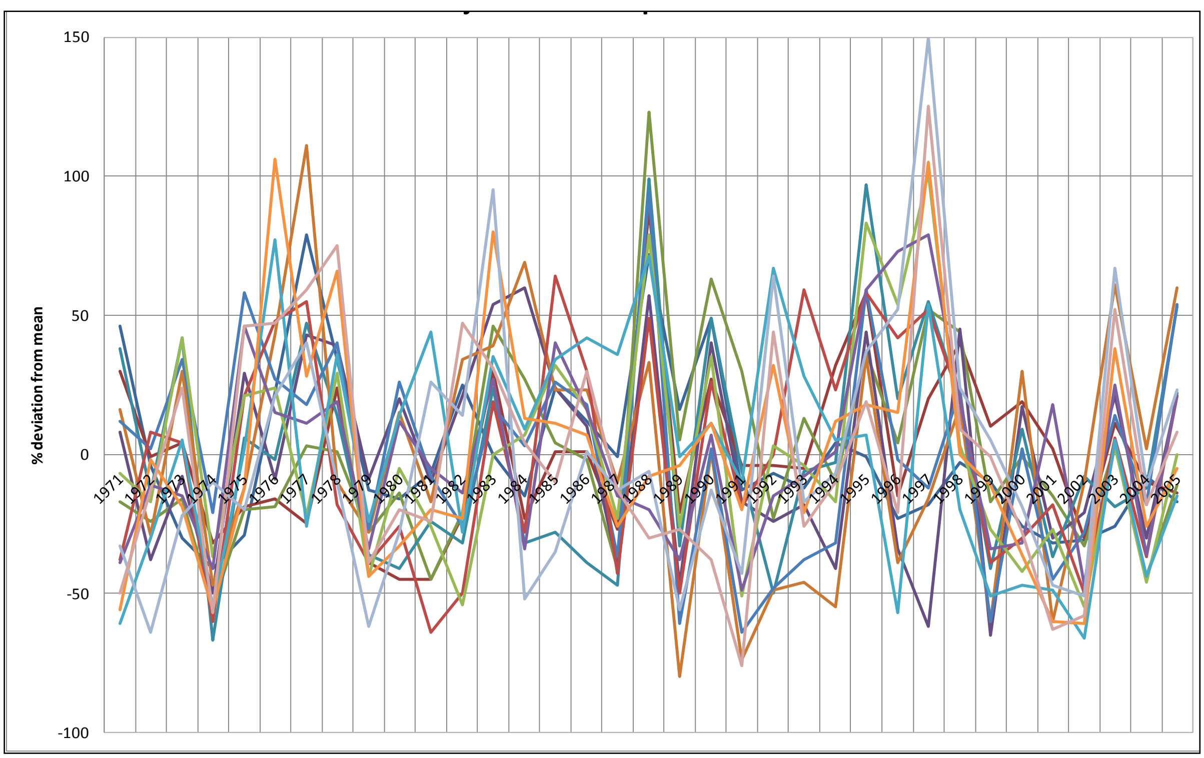
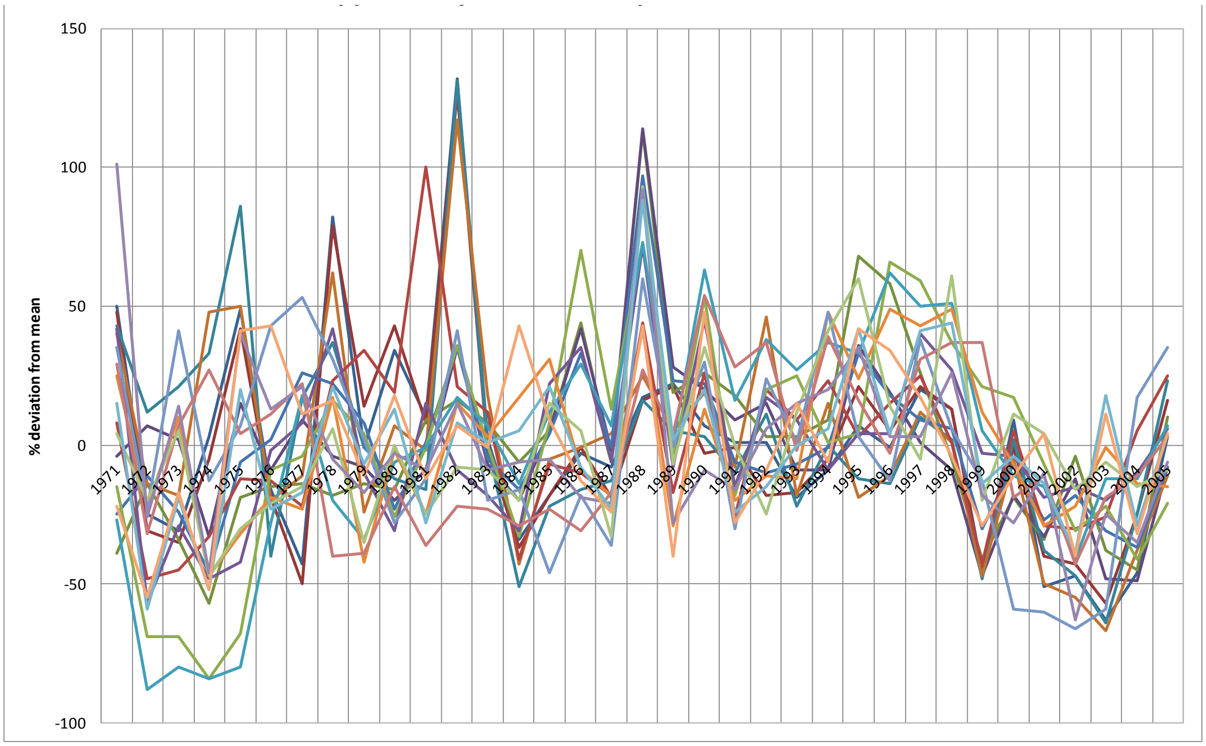
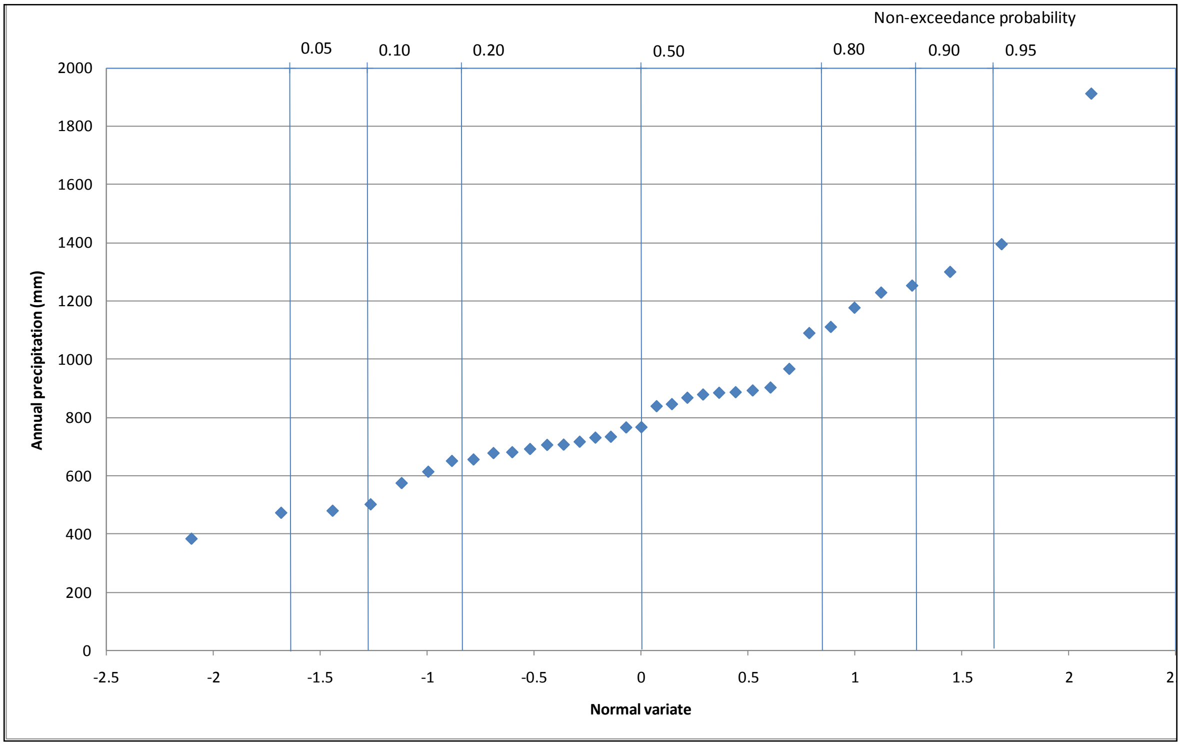


Figure 10 Deviations from Mean of Annual Rainfall at all IMD grids in the Upper Sutlej Basin



24. Figure 11 presents the annual precipitation data for IMD grid 76.0oE 31.0oN plotted in normal probability space. The data do not fit well to a normal distribution, but it is of interest to note the variance. The annual rainfall at 20% non-exceedance probability is about 650 mm, while that at 80% non-exceedance probability is 1100 mm. The significance of this is that inter-annual variability in irrigation demands will be high.

Figure 11 Annual precipitation at IMD Grid 76.0°E 31.0°N



2. Seasonal Precipitation

25. Seasonal precipitation has been analysed in a similar way to that of annual precipitation. For the purposes of analysis, seasons were defined as March, April, May (MAM); June, July, August, September (JJAS); October, November (OND); January, February (JF).

26. Figure 12 shows mean precipitation for the four periods. It can be seen that. approximately 80% of the annual rainfall in the lower basin occurs in shows the mean JJAS precipitation, in contrast in the upper basin where about 40% of the annual precipitation occurs in JJAS

27. Figure 13 shows the coefficients of variation in precipitation. Precipitation clearly decreases significantly from north to south, while coefficients of variation increase significantly from north to south, as might be expected with the very low rainfall totals in the lower basin. Coefficients of variation in JJAS precipitation are significantly lower than in MAM, and the data are less skewed.

28. Figure 14 shows deviations from the mean of MAM precipitation at all IMD grids for the 1971 to 2005 period. The data are significantly skewed, and there is more spatial consistency in wet and dry years than was apparent in the annual data. Figure 15 shows the deviations from the mean for JJAS.

29. The ON season is driest throughout the basin. In many years parts of the lower basin receive no precipitation in this period. In the DJF season there is significantly more precipitation in the upper basin, but still little precipitation in the lower basin. In the upper basin precipitation is in the range of 100 mm to 200 mm, while in the lower basin it ranges from 10 mm in the southwest to almost 70 mm in the vicinity of Ropar headworks. Variability is significantly higher in the lower basin than in the upper basin.

Figure 12 Mean Precipitation in the Sutlej Basin (1971-2005)

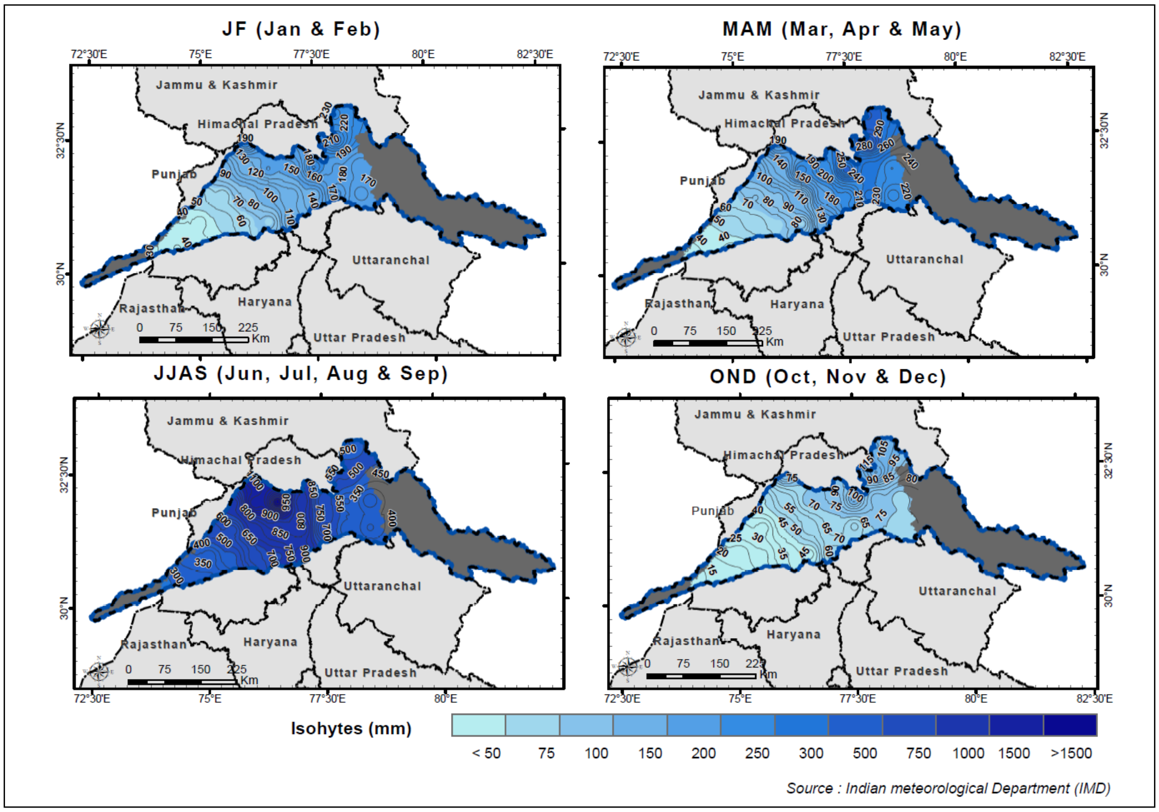


Figure 13 Coefficient of Variation of Rainfall in Sutlej Basin

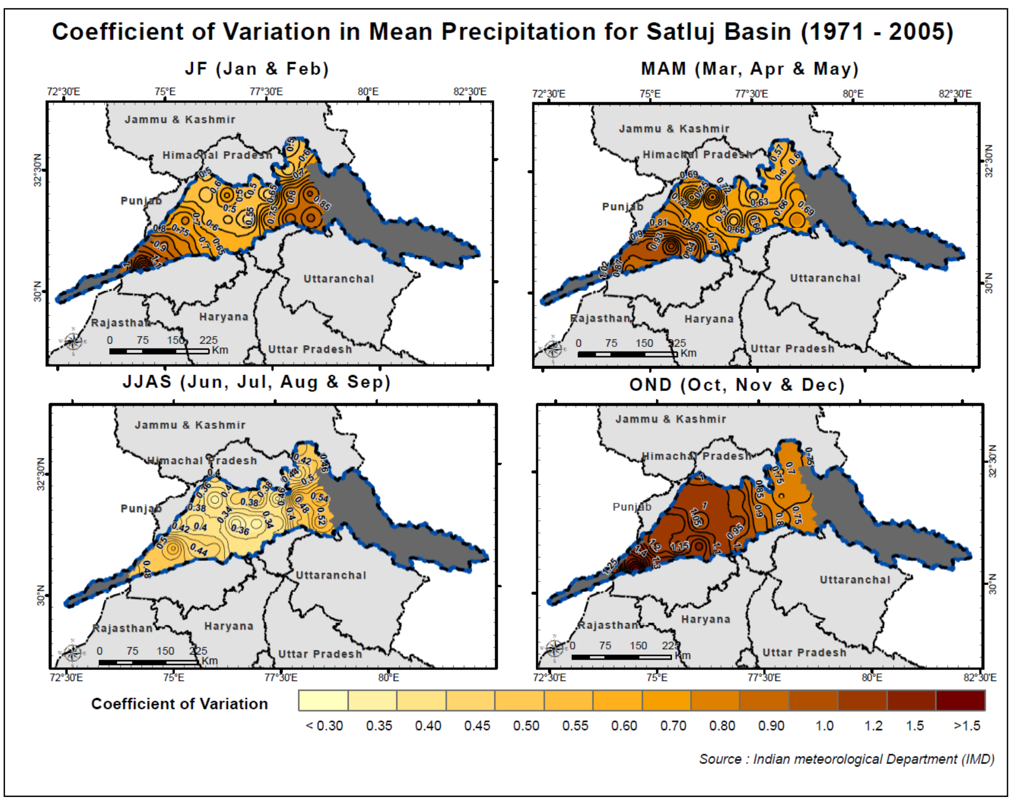


Figure 14 Deviations from the mean of MAM precipitation at all IMD Grids

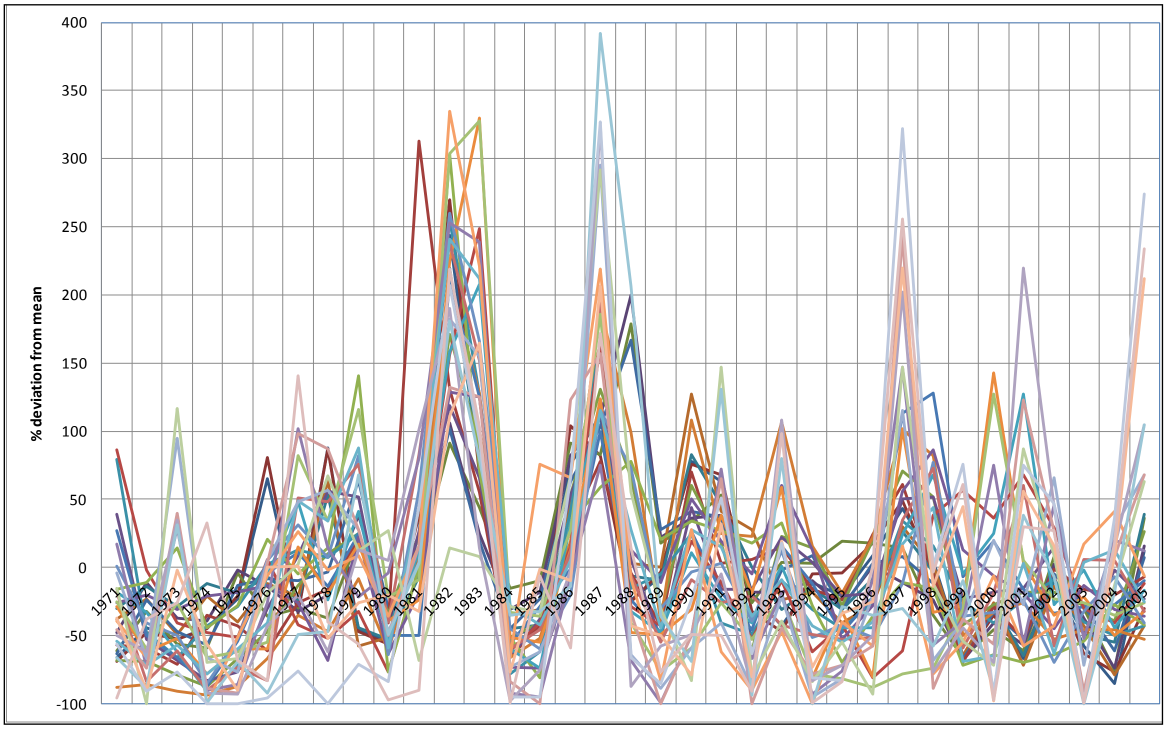
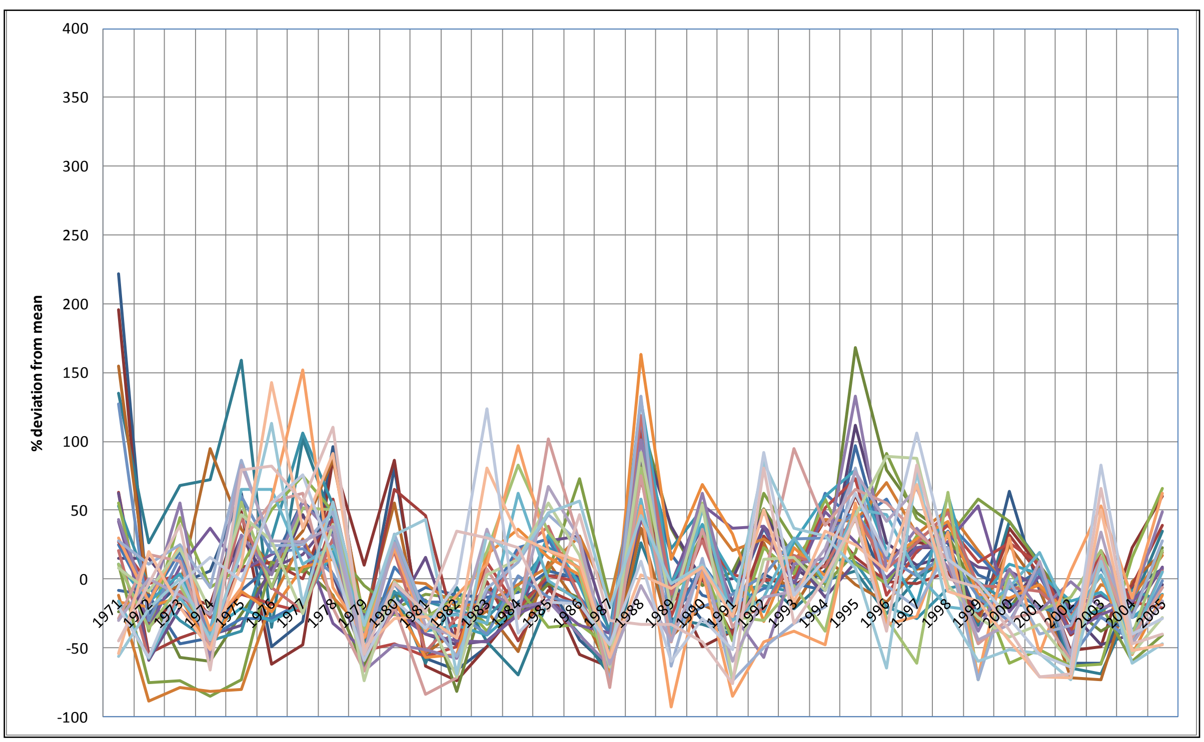


Figure 15 Deviations from from the mean of JJAS precipitation at all IMD grids



3. Drought Characteristics

30. An analysis has been made of drought durations with a 10 mm precipitation threshold in the Kharif (JJAS) and Rabi (ONDJF) season. The mean annual drought durations are shown in Figure 16 and Figure 17. This analysis is of most interest in the lower basin, where it is indicative of agricultural risk and irrigation needs. In the Kharif season, mean annual drought durations vary from 23 days in the vicinity of Ropar headworks, to 46 days in the southwest of the Sirhind command, where potential evapotranspiration is also highest. The range in drought durations during the Rabi season is less significant, and clearly periods of over 3 months with virtually no precipitation in the Rabi season are common throughout the lower basin.

31. The time series of annual droughts with a 10 mm threshold in the Kharif season on IMD grids in the lower basin are shown in Figure 18. Clearly drought duration can vary significantly across the lower basin in any particular year. There is an indication from Figure 19 that droughts in the southwest of the lower basin may be becoming more extreme. Further analysis was therefore carried out considering only IMD grids 73.5°E 29.5°N in the southwest and 76.5°E 31.0°N which is closer to Ropar headworks. Plots of the deviations from the mean of annual 10 mm Kharif drought durations are shown in Figure 19 and Figure 20 The indication is that there could be a trend of increasing drought intensity in the southwest, but there is no apparent trend in the vicinity of Ropar. The records analysed are not considered long enough to establish the existence of long term trend, and for this reason statistical tests have not been carried out.

Figure 16 Kharif Season Mean Drought Durations

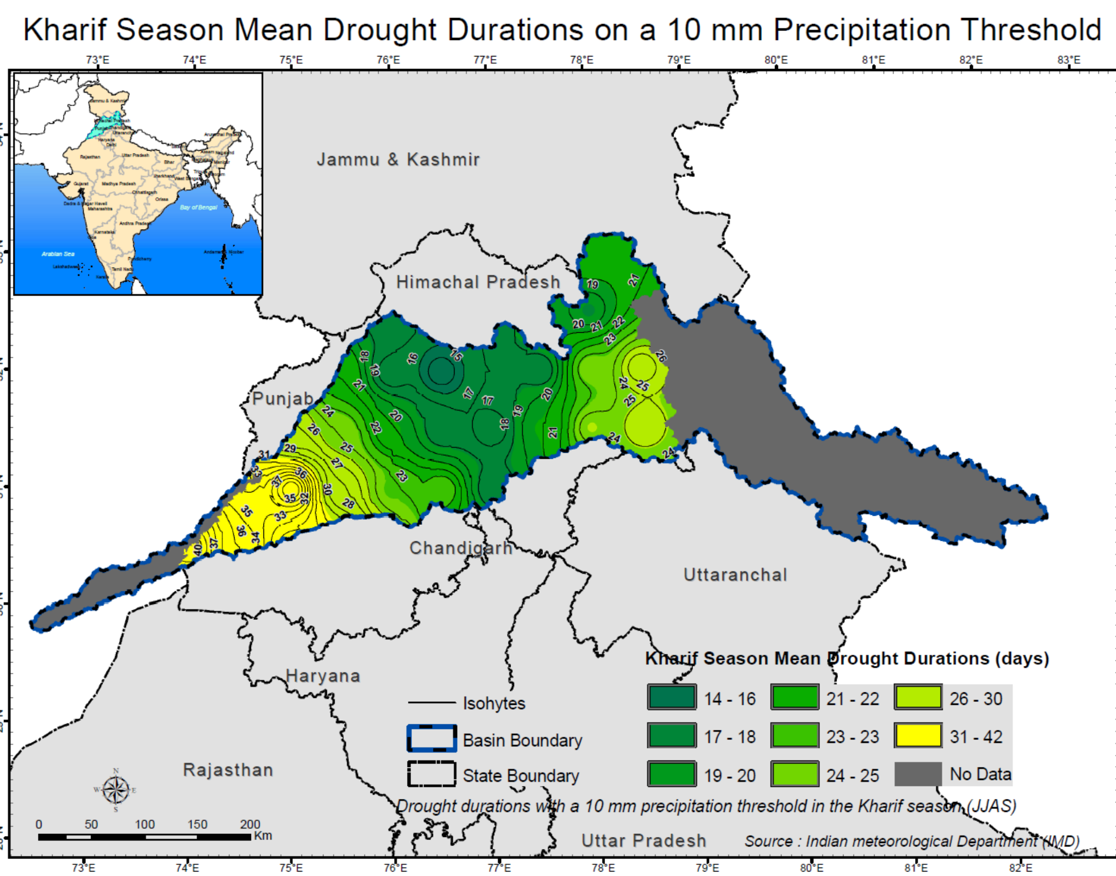


Figure 17 Rabi Season Mean Drought Durations

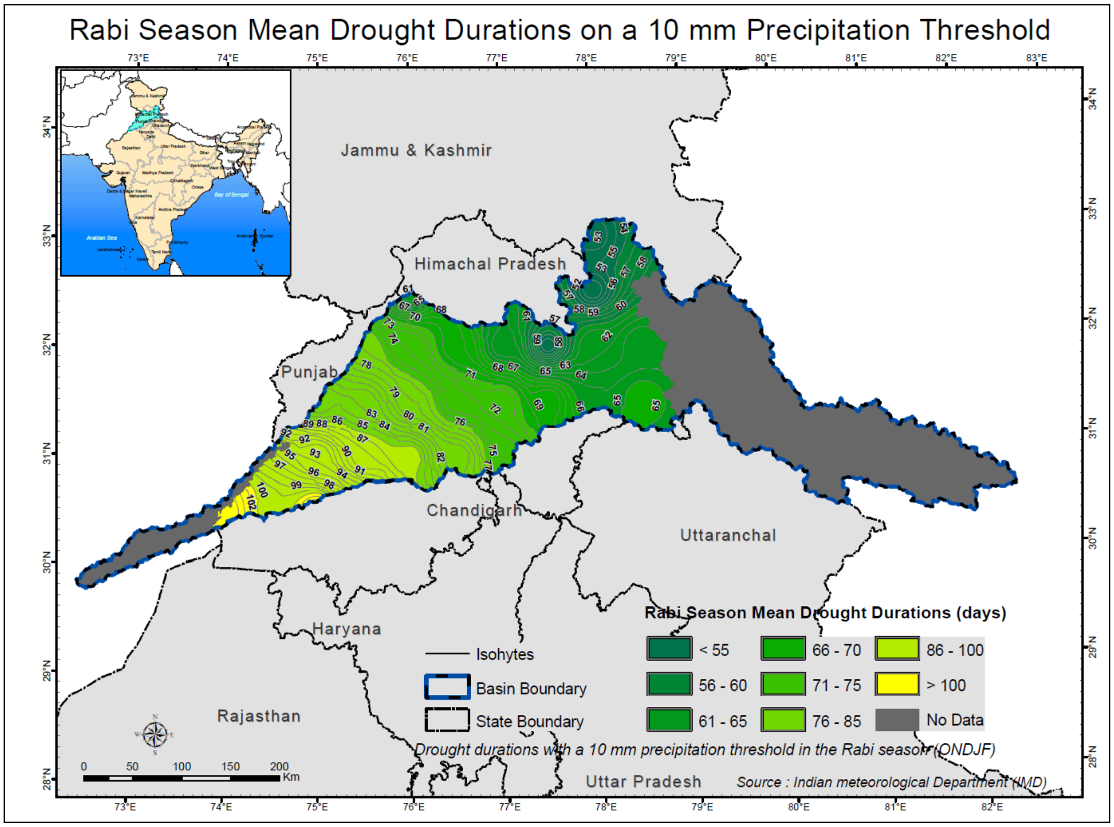


Figure 18 IMD Grids Annual Kharif Drought Durations 10mm Threshold

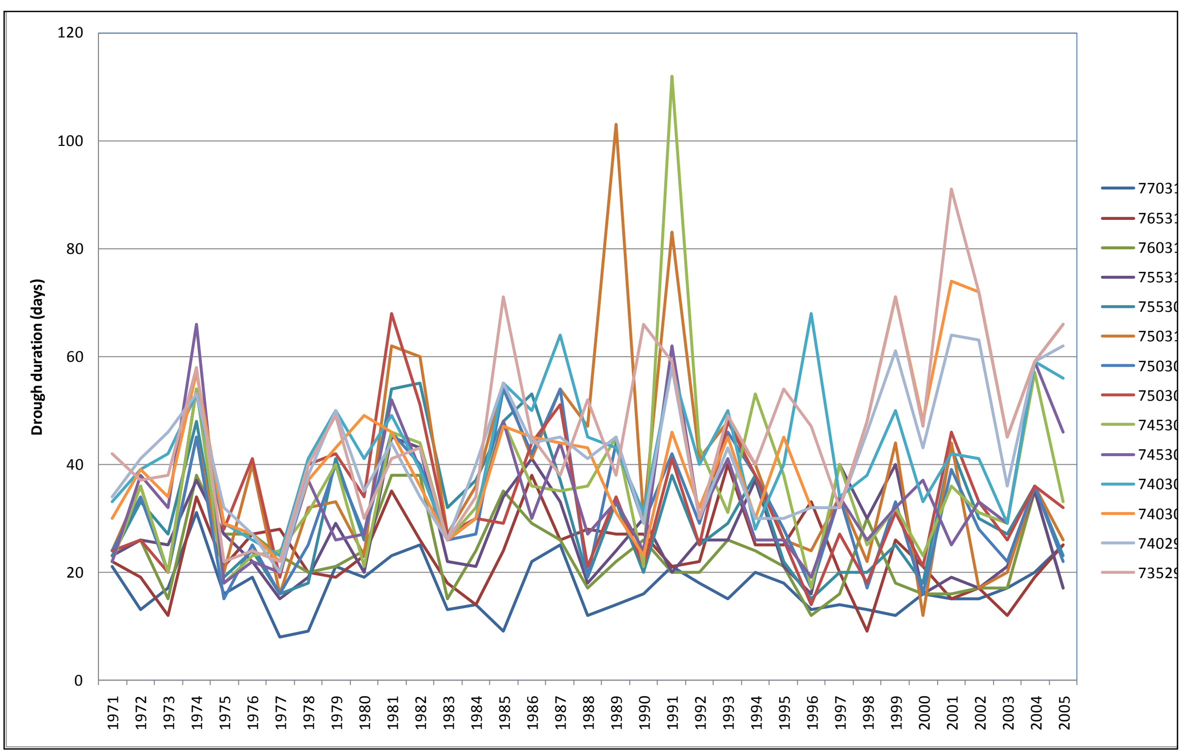


Figure 19 Deviation of Drought Durations in Southwest of Sirhind Command

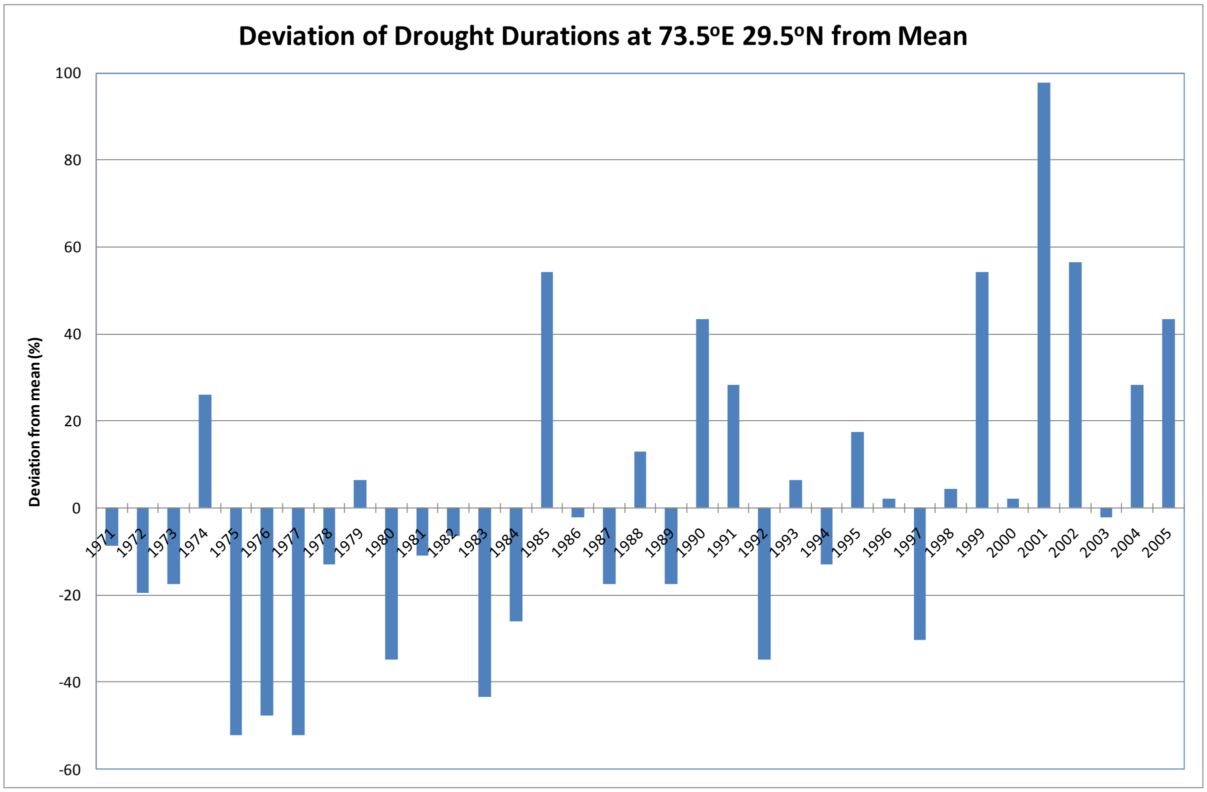
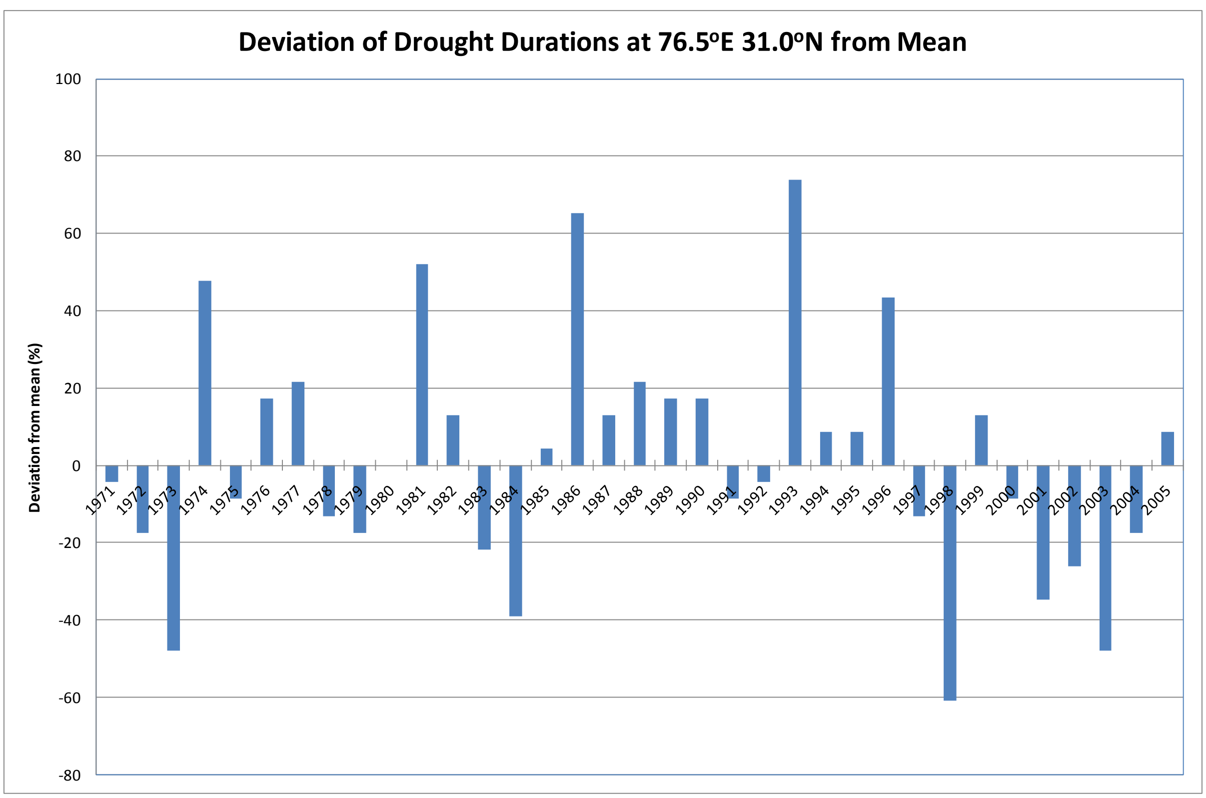


Figure 20 Deviation of Deviations from the mean of drought durations in the vicinity of Ropar Headworks

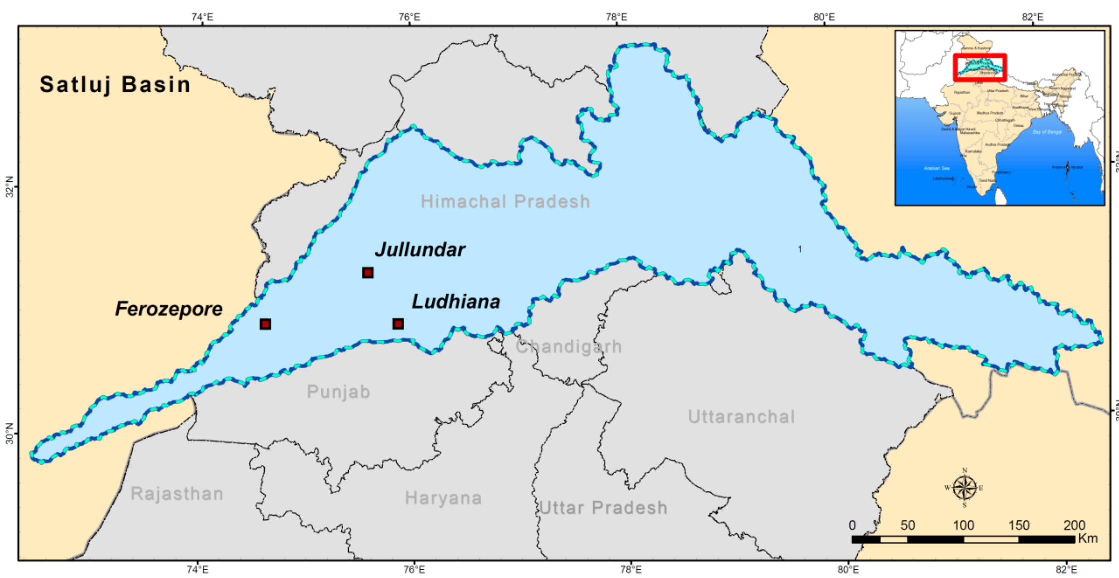


D. Trends in Annual and Seasonal Rainfall

1. Introduction

32. Tests for trend have been made with data for three IMD raingauges in the lower Sutlej. IMD made data available for the period from 1971 to 2005. The stations used were Ferozepore , Jullandar and Ludhiana. Their locations are shown in Figure 21. Thirty five years of record is rather short for long term trend analysis and for the record at Ludhiana, it was possible to extend the record using data archived by GHCN (GHCN precipitation[3]).

Figure 21 Locations of IMD Observed Rain Gauge Stations



33. The Mann-Kendall test has been used in trend analysis. The Mann-Kendall test is a non-parametric test for identifying trends in time series data. The test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987[4]). One benefit of this test is that the data need not conform to any particular distribution.

34. The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, S, is assumed to be 0 (no trend). If a data value from a later time period is higher than a data value from an earlier time period, S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S. Mann-Kendall statistic (S) is given by

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k)$$

[3] http://www.ncdc.noaa.gov/oa/climate/ghcn-daily/

[4] Gilbert, R.O., 1987. Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold, New York. Kendall, M.G., 1975. Rank correlation methods, 4th ed. Charles Griffin, London

where: x_1, x_2,….x_n represent n data points, where x_j represents the data point at time j.
sign(k_j-x_k) = 1 if $k_j - X_k > 0$; = 0 if $k_j - X_k = 0$; = -1 if $k_j - X_k < 0$

35. A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend.

2. Data Quality.

36. A large number of missing values were found in the IMD records of all three stations. At Ferozepore and Jullandar there were no data for 1971, or after 2002, and in fact for 2002 only two months were available. At Ferozepore there were no data for 1986. At Ludhiana there were no data from 1985 to 1987 and very little data for 1984 and 1988. Even after excluding complete and almost complete missing years of data there were 690 missing records at Ferozepore, 537 missing records at Jullandar, and 514 missing records at Ludhiana. In contrast there were only 39 missing records in the 70 years of daily data obtained from GHCN for Ludhiana. There has clearly been a significant deterioration in data quality post 1970. It was not possible to explore data quality issues further, but efforts are required to improve data quality.

3. Test Results

37. The results of the Mann-Kendall trends analysis for the 3 IMD stations using the post 1970 IMD data for Forozepore and Jullandar, and the composite GHCN/IMD data for Ludhiana, are summarised in Table 2, Table 3 and Table 4. Generally in the evaluation of these tests, a significance level of less than 0.05 would indicate the existence of trend, or there would be 95% confidence in the existence of trend.

38. At Ferozepore there is no statistically significant trend in either annual or seasonal rainfall. At Jullandar the indication is for a very mild trend of increasing annual rainfall, with a significance level of 0.11. Interestingly the trend is less significant during the southwest monsoon, when the significance level approaches 0.20 than during the northeast monsoon. Figure 22 shows the annual rainfalls at Jullandar. Although a trend line is plotted, this would not be considered to be statistically significant.

At Ludhiana there is evidence of a statistically significant increasing trend in southwest monsoon rainfall. There is also trend in the annual and northeast monsoon rainfalls with significance levels of 0.06. However, this trend is influenced by a period of above average rainfalls following a four year gap in the record. It is possible that there may have been some change in exposure of the raingauge following the four years of missing record, and this result should be considered cautiously.

39. Figure 23 shows the annual Long term rainfall at Ludhiana with the trend line plotted.

Table 2 Annual Rainfall Trends

Stations	**Basin**	**Linear equations**	**Mann-Kendall test statistics (Calculated z)**	**Significance level**
Ferozepore	**Sutlej**	**y = -3.3269x + 698.45**	**-1.00**	**> 0.30**
Jullandar	**Sutlej**	**y = 10.879x - 156.81**	**1.58**	**> 0.10**
Ludhiana	**Sutlej**	**y = 1.6881x + 617.54**	**1.86**	**>0.05**

Table 3 Seasonal Rainfall Trends, southwest monsoon (June - September)

Stations	Basin	Linear equations	Mann-Kendall test statistics (Calculated z)	Significance level
Ferozepore	Sutlej	y = -3.9028x + 666.07	-1.00	> 0.30
Jullandar	Sutlej	y = 9.2656x - 211.55	1.29	>0.10
Ludhiana	Sutlej	y = 1.9146x + 457.07	2.01	<0.05

Table 4 Seasonal Rainfall Trends, southeast monsoon (October - December)

Rainfall Stations	Basin	Linear equations	Mann-Kendall test statistics (Calculated z)	Significance level
Ferozepore	Sutlej	y = 0.1334x + 28.94	-1.00	> 0.30
Jullandar	Sutlej	y = -0.581x + 139.01	1.58	> 0.10
Ludhiana	Sutlej	y = 0.0635x + 53.836	1.86	>0.05

Figure 22 Annual rainfall record at Jullandar

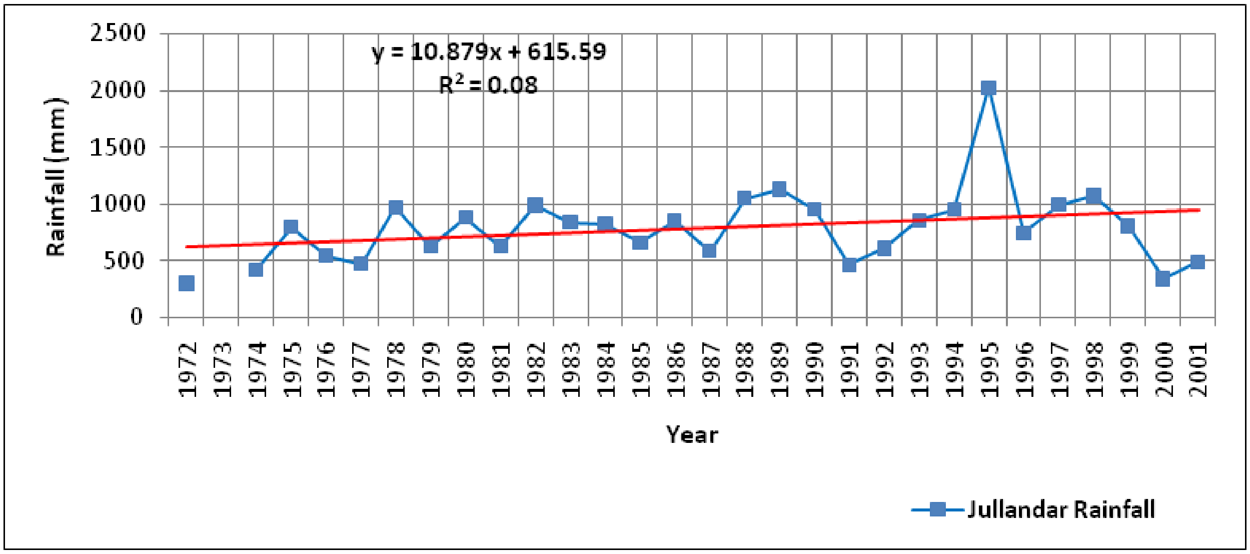
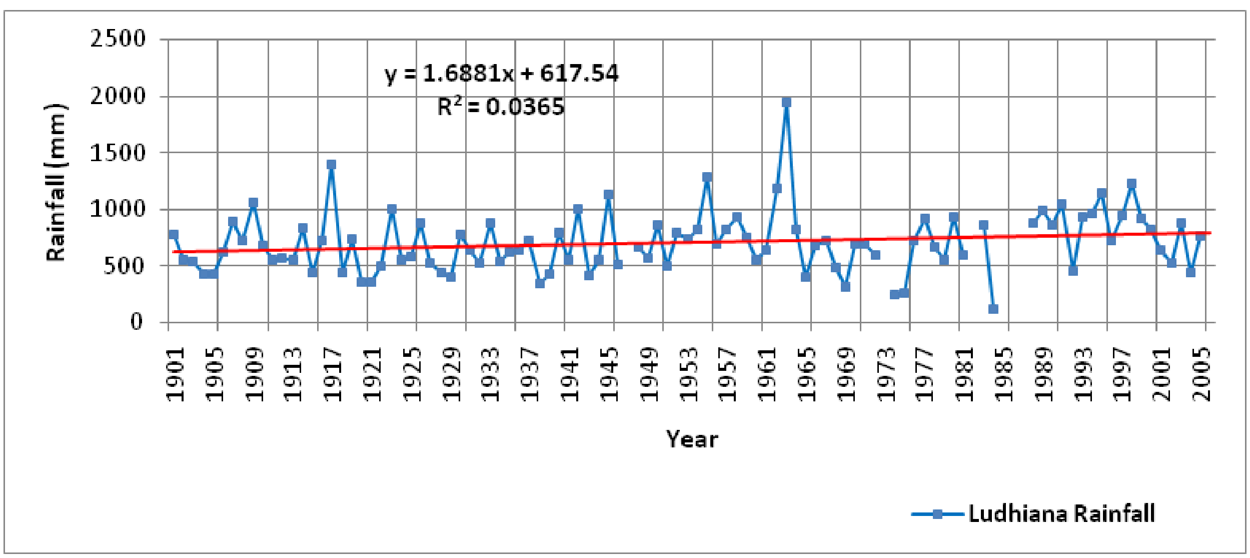


Figure 23 Annual rainfall record at Ludhiana (composite)



E. River Flows and Water Resources Assessments

40. The surface water resource of the Sutlej basin is effectively that of the basin upstream of Bhakra reservoir. Records exist of inflows to Bhakra reservoir from the Sutlej River from 1962. The BSL came

into operation in 1977. The mean annual inflow from the Sutlej River in the period April 1962 to March 2009 was 14,450 Mm^3. The mean annual inflow from the BSL in the period April 1978 to March 2009 was 4345 Mm^3. The coefficient of variation in annual inflows from the River Sutlej is 0.16. The variance in annual inflows is significantly lower than the variance in annual precipitation, and this will be as a result of the influence of snow and glacier melt.

41. Figure 24 shows a plot of annual deviations from the mean of annual inflows to Bhakra from the Sutlej River. It is apparent that in the last decade, annual inflows have been below average, corresponding with below average precipitation in this period. A number of statistical tests have been carried out on the annual inflow series, and these are summarised in Table 5. It is apparent that the data are random, and that there is no significant evidence of persistence or trend in the data.

Table 5 Statistical tests on Bhakra Reservoir inflows from the Sutlej River

Test	Expected (for a Random Series)	Observed
Randomness Tests		
NUMBER OF MEDIAN-CROSSES	23 +/- 9	26
NUMBER OF TURNING-POINTS	30 +/- 5	47
Persistence Tests		
FIRST-ORDER SERIAL CORRELATION	-0.02 +/- 0.29	-0.31
SPEARMAN RANK TEST	-0.02 +/- 0.29	-0.34
Trend Tests		
RANK ORDER TEST	-0.02 +/- 0.29	0.18
MANN-WHITNEY U TEST	276 +/- 92	237
WALD-WOLFOWITZ RUNS TEST	24 +/- 7	28

42. The annual inflows to Bhakra Reservoir from the Sutlej River are shown plotted in normal probability space in Figure 25 The data fit well to a normal distribution. At 20% non-exceedance probability the annual inflow from the Sutlej River is 12,400 Mm^3.

43. Outflow and inflow data for Bhakra reservoir were available for the period 21st May 1980 to 20th May 2009. During this period, the mean annual inflow from the Sutlej River and et BSL was 18,608 Mm^3, and the mean annual outflow 18,608 Mm^3. It would appear therefore that reservoir precipitation and evaporation, and seepage losses are neutral. There are small differences year on year between inflows and outflows, but these are not significant. Bhakra Reservoir does not provide any over-year storage, only seasonal storage is provided.

1. Storage at Bhakra

44. The Bhakra dam is able to provide a major buffer to the uncertainties of the river flow both under present and projected under climate change. The development of water resources in Himachal will have quite limited effect on the water in Punjab. The irrigation and water supply demands are insignificant in relation to the water availabilities and the available storage at Bhakra. Most of the hydropower schemes are run of the river and do not affect the flow regimes. The Kol Dam presently under construction will have a storage of 575MCM, the proposed Khab Dam would have a storage of 95MCM. The storages of both of these dams is quite small Bhakra (9867MCM); the extra storage would primarily be dead storage to reduce silt and benefits to the reduce flood flows and support dry season availability maybe limited. There is no information on planned water resources development in PR. China.

45. **Sediment**; of significance is the sediment. The results of surveys of the Bhakra dam in 1996/7 30 years after initial filling show the loss of dead and live storage. Silt is being deposited at the top end of the long reservoir and is reducing both the dead and live storages. The Kol dam presently under construction has quite small storage primarily as dead storage to retain silt. The proposed 275m Khab dam will include 95 MCM storage designed to arrest the 12MCM of silt brought down annually by the upper Sutlej and Spiti rivers; the estimated life of the dam would be 28 years.. It has been calculated that the Khab dam would increase the life of the Bhakra reservoir by nine years and that of Kol Dam reservoir by 14 years.

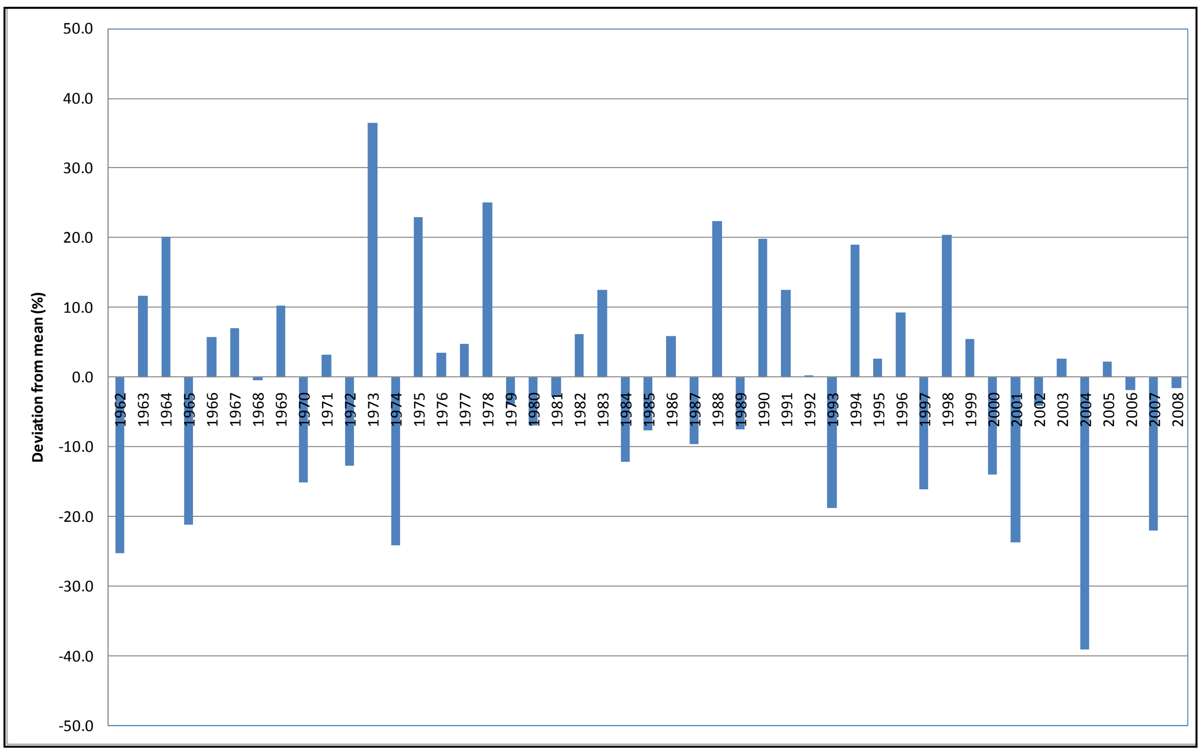
Further, two more dams are under consideration upstream on the Spiti River at Rangrik and Pooh to enhance the life of the Khab Dam reservoir.

46. A summary of the storage volumes at Bhakra[5] is presented in Table 6. The 2008 current gross storage of Bhakra reservoir at normal top operating level is 8519 Mm3. BBMB completed a reservoir survey in June 2008, from which they concluded that about 25% of reservoir live storage capacity would be lost in about 150 years. To mid-century it would be reasonable to assume a 10% loss in live storage. It would appear that loss of storage is not a significant problem.

Table 6 Storage at Bhakra

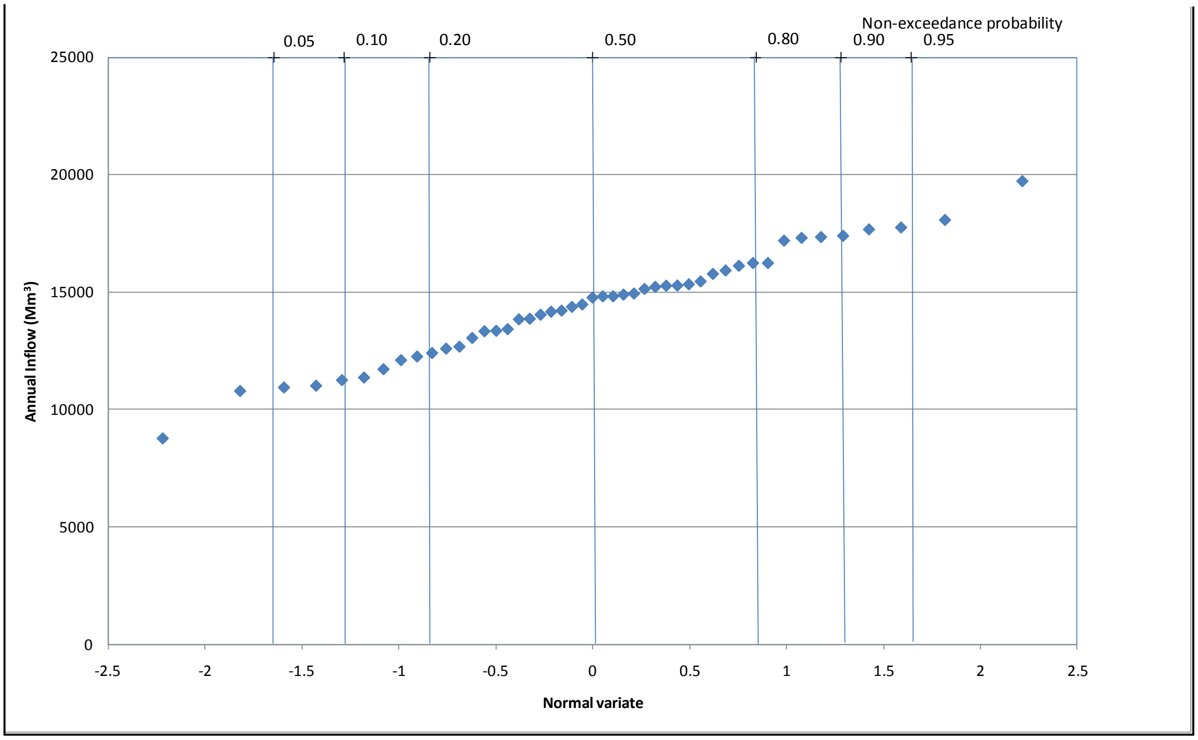
Nr years from construction	Dead Storage(MCM)			Live Storage(MCM)		Total storage (MCM)
	Year	Dead Storage(MCM)	%	Live Storage(MCM)	%	
0	Original 1965	2,431	100	7,436	100	9,867
31	BBMB 1996/97	1,763	73	6,769	91	8,590
43	BBMB 2008	1,531	63	6,512	87	8,043

Figure 24 Deviation of the Mean Annual Flows to Bhakra Reservoir



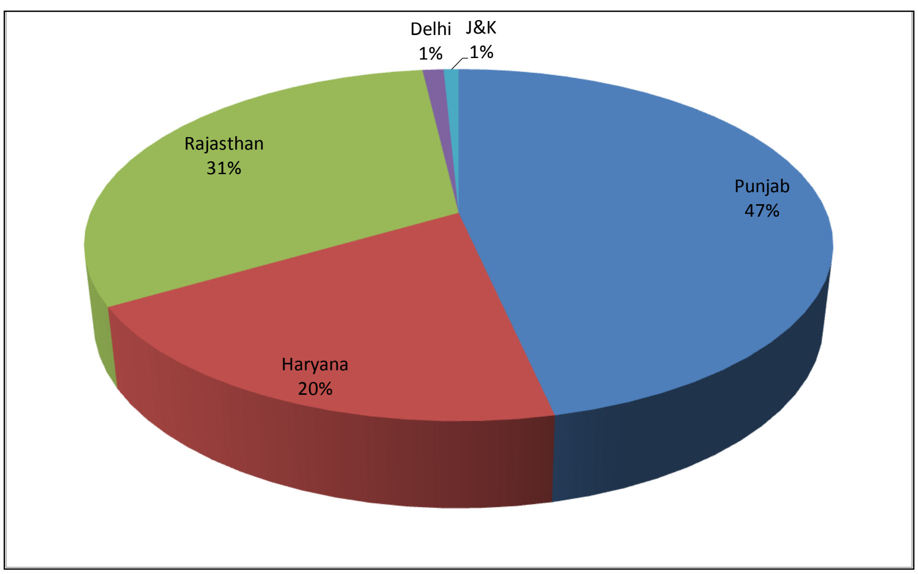
[5] Bhakra Beas Management Board

Figure 25 Annual Inflow to Bhakra Reservoir



48. Supply of water to the States of Punjab, Haryana and Rajasthan is reported in terms of Sutlej and Beas water. It would appear that the reported Sutlej flows are not Bhakra Reservoir releases that would include BSL flows, but relate to the resource of the Sutlej River. Each state has an allocated share of Sutlej and Beas water. The average deliveries of available supplies are shown in Figure 26.

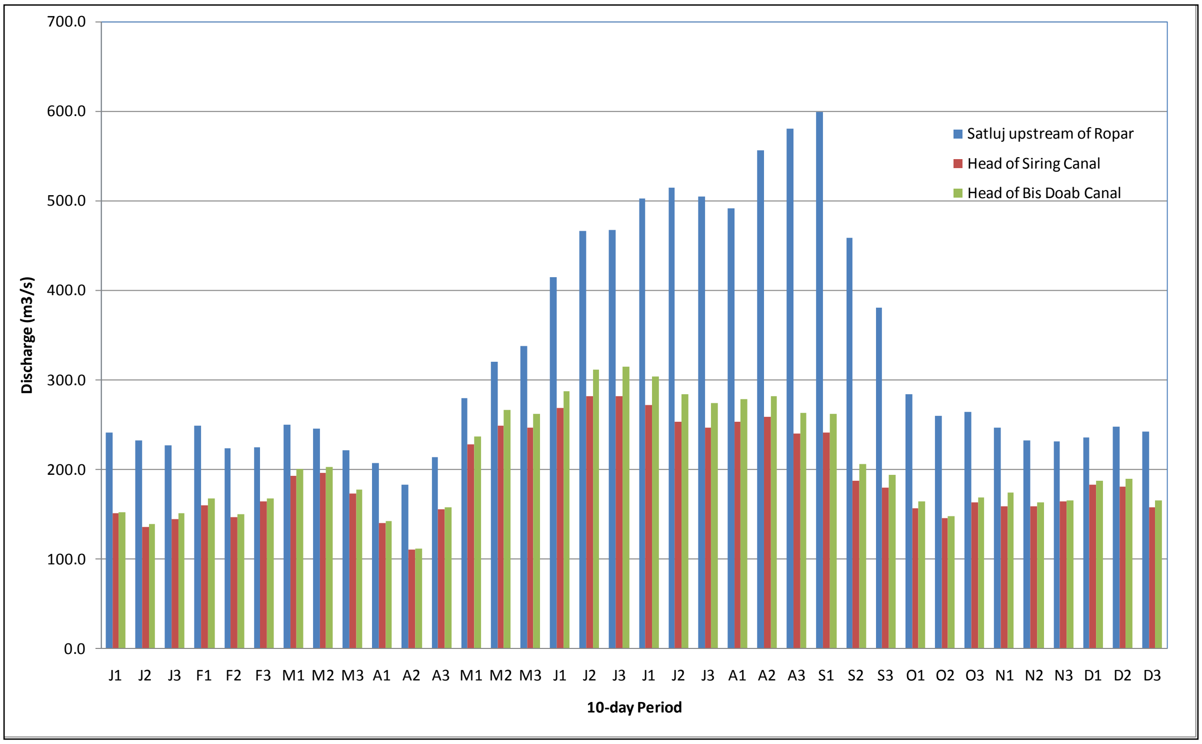
Figure 26 Average Distribution of Sutlej and Beas Water



49.

50. The mean annual water volume arriving at Ropar headworks in the period 1990 to 2010 was 10,360 Mm^3. On average, 60% of this water is diverted into the Sirhind command area, just less than 4% to the Bis Doab canal, and the remainder is passed downstream. Figure 27 shows the mean 10 day flows in the Sutlej River at Ropar. The higher flows in August and early September indicate that the reservoir is often spilling at this time. No analysis has yet been possible of reservoir records. In the dry season there is little flow in the river downstream of Harike.

Figure 27 Mean 10 day DIscharges at Ropar Headworks



II. REVIEW OF SNOW AND GLACIER HYDROLOGY

A. General

51. The Himalayan mountain system is the source of one of the world's largest supplies of freshwater. All the major river systems in south Asia originate in the Himalayas. The presence of snow and glaciers in the upper part of the Himalayan basins form a unique reservoir of fresh water supporting rivers such as the Indus, Ganga and Brahmaputra, which are the lifeline of millions of people. The water flowing in these Himalayan rivers is a combined flow from rain, snow and glaciers. Snow and glacier runoff plays a vital role in making all these rivers perennial, whereas the rainfall contribution during monsoon period is critical for storages in various reservoirs. The summer and spring runoff, comprising mostly of snow melt and glacier melt is a source of water for irrigation, hydroelectric power production and drinking water supply. Melt water replenishes stock ponds, infiltrates the soils, and recharges the ground water. The runoff generated from the ground water storage becomes important during the lean season. The water yield of a high Himalayan basin is roughly double that from an equivalent basin area located in the peninsular part of India. This higher water yield is mainly due to the large inputs from the snow and glaciers.

52. There are about 9,575 glaciers in the Indian territory, occupying about 38,000 km2 area of the Himalayas[6] (GSI, 1999). The Sutlej river basin consists of 945 glaciers with an cumulative area of about 1218 km2 and estimated ice reserve of about 95 km3 (ICIMOD and others, 2004). Existence of snow and glacier fields in the Himalayas is mainly because of their ultra high altitudes, which compensates for such a large glaciation extent at low latitudes. The concentration of glaciers is higher in the western Himalayas than the eastern Himalayas. Himalayas contain the largest number of glaciers in the world outside the Polar circles. The glaciations in the Himalayas are found to be more intense than the Alps and Rockies. The Himalayan glaciers have a large variation in their size. There is a lack of data and information on glaciers in India, mainly due to lack of comprehensive studies. It has resulted in poor long-term data availability regarding Himalayan glaciers as well as regarding runoff being generated from glaciers.

53. Glaciers are considered to be very sensitive to the climatic conditions. Retreat of glaciers and its impact on water resources is one of the current issues being debated for more than two decades. There is evidence that glaciers have retreated globally during the last century. At present deglaciation is considered to be a world-wide problem including the Himalayan region. Glaciers also preserve climatic signatures, which can be used to reconstruct past climatic records. Records available for the Himalayan glaciers also suggest retreat of glaciers.

B. Streamflow Characteristics Of Himalayan Rivers

54. The spatial distribution of runoff for the Himalayan basins shows that contribution from rain dominates in the lower part of the basins (< 2000 m). Heavy rainfall during the monsoon season contributes represents about 70% of total annual rainfall in these areas. The middle and upper parts of the basins (> 2000 m) have contribution from both rain and snowmelt and their contribution changes with altitude. As the elevation of the basin increases, the contribution from rain reduces, but snow melt contribution increases. Runoff is dominated by the snow melt runoff above 3000 m altitude. Runoff is dominated by the glacier melt for all the upper parts of the basin above 4000 m altitude. In general snow melt during spring (March-April) provides a high proportion of the runoff. Hydrological observations carried out for the glacierized basins in the Himalayan region indicate that melting of the glaciers takes place from May to October and maximum runoff from these basins is received during July and August (Singh et al., 2006). Studies indicate that maximum rainfall in the Himalayan basins takes place around 1500 m on

[6] Geological Survey of India

the windward slopes of the mountains[7] reported that summer and annual runoff of the high altitude glacierised catchments are strongly dependent on the seasonal temperature, while summer flow of the middle altitude catchments is predominantly controlled by the preceding winter precipitation. The runoff regime of foothill catchments is mainly controlled by rainfall, predominantly in winter but also during the monsoon.

C. Snow and Glacier Melt Contribution

55. Snow and glacier melt runoff contributes substantially to the annual flows of these rivers and its estimation is required for the planning, development and management of the water resources of this region. Some studies to estimate snow and glacier contribution into the annual flows of few Himalayan rivers have been carried out in India. Table 7 presents snow and glacier contributions into annual flows of Himalayan rivers area at the gauging sites in the foothills of the Himalayas along with maximum and minimum snow covered area. It is clear that all these sites receive significant contribution from snow and glacier melt runoff in the stream flows. The role of glaciers and snow cover in controlling the headwater river run-off variability of areas under the influence of monsoon shows the Sutlej j river has the highest percentage contribution of snow and glacier melt[8] .

Table 7 Snow and glacier melt contributions in some Himalayan rivers

River Basin	Catchment area (km^2)	Snow cover area (km^2)		Snow and glacier contribution in annual flows (%)	Sources
		Max.	Min.		
Ganga (up to Deoprayag)	19700	9080 (40.9%)	3800 (19.3%)	29%	Singh et al. (1993)
Chenab (up to Akhnoor)	22200	15590 (70.2%)	5400 (24.3%)	49%	Singh et al. (1997)
Sutlej (up to Bhakra Dam, Indian Part)	22305	14498 (65.0%)	4528 (20.3%)	60%	Singh and Jain (2002)
Beas (up to Pandoh Dam)	5278	2375 (45%)	780 (15%)	35%	Kumar et al. (2007)

[7] Singh, P. and Bengtsson, L. (2003). Effect of warmer climate on the depletion of snow covered area in the Sutlej Basin in the western Himalayan region. Hydrological Sciences Journal, 48(3), pp. 413-425.
Singh, P. and Bengtsson, L. (2004). Hydrological sensitivity of a large Himalayan basin to climate change. Hydrological Process (18), pp. 2363–2385; Singh, P. and Bengtsson. L. (2005).Impact of warmer climate on melt and evaporation for the rainfed, snowfed and glacierfed basins in the Himalayan Region. Journal of Hydrology (300), pp. 140-154.
[8] Thayyen, R.J., Gergan, J.T. and Dobhal, D.P. (2007). Role of glaciers and snow cover on headwater river hydrology in monsoon regime – Micro-scale study of Din Gad catchment, Garhwal Himalaya, India. Current Science (92), pp. 376-382.

D. Climate Change Impacts on the Himalayan Region in India

1. Trend Analysis for Precipitation, Temperature and Snow cover

56. The focus of the studies for trend analysis in the Himalayan region mainly had been on the precipitation and temperature using sparse data. Temperature data for seven instrumental records in the Karakoram and Hindu Kush Mountains of the Upper Indus Basin was analyzed by Fowler and Archer (2006) for seasonal and annual trends over the period 1961–2000 and compared with neighbouring mountain regions and the Indian subcontinent. Strong contrasts were found between the behaviour of winter and summer temperatures and between maximum and minimum temperatures. Winter mean and maximum temperature showed significant increases while mean and minimum summer temperatures showed consistent decline. Increase in diurnal temperature range (DTR) was consistently observed in all seasons and the annual dataset, a pattern shared by much of the Indian subcontinent but in direct contrast to both GCM projections and the narrowing of DTR seen worldwide. This divergence commenced around the middle of the twentieth century and is thought to result from changes in large-scale circulation patterns and feedback processes associated with the Indian monsoon.

57. Bhutiyani et al. (2007) [9] found significant rise in air temperature in the northwest Himalayan (NWH) region by about 1.6°C in the last century, with winters warming at a faster rate. The diurnal temperature range (DTR) also showed a significantly increasing trend. This appears to be due to rise in both the maximum as well as minimum temperatures, with the maximum increasing much more rapidly. The results are in contrast to the findings in the Alps and Rockies where the minimum temperatures have increased at an elevated rate. Conforming to the global trends, the study confirms episodes of strong warming and cooling in the NWH in the last century. Real warming appears to have started from late-1960s and highest rate of increase was experienced in the last two decades. The study also shows teleconnections between temperatures and an epochal behaviour of the precipitation till late-1960s. These teleconnections seem to have weakened gradually since then and rapidly in the post-1991 period, indicating the waning effect of the natural forcings in this period.

58. Basistha et al. (2009)[10] investigated the changes in rainfall pattern in the Indian Himalayas focusing on Uttarakhand State during 20th century using 80-year data from 30 rain gauge stations maintained by the India Meteorological Department (IMD). Rainfall was found decreasing during last century as a sudden shift, rather than gradual trend. The most probable year of change in annual as well as monsoon rainfall is estimated is 1964. The period 1902–1964 showed mostly an increasing trend, which reversed during 1965–1980?

59. Negi et al. (2009) carried out snow cover monitoring to evaluate the region-wise accumulation and ablation pattern of snow cover in Pir Panjal and Shamshawari ranges of Kashmir valley. This has been validated with 20 years (1988–89 to 2007–08) climatic conditions prevailed in both ranges of Kashmir valley. Region-wise study showed the spatial and temporal variability in seasonal snow cover within Kashmir valley. Advance melting was observed in Banihal and Naugam/Tangdhar regions than Gurez and Machhal regions. Different geographical parameters of these regions were studied to evaluate the influence on snow cover and it was observed that altitude and position of region with respect to mountain range are the deciding factors for retaining the seasonal snow cover for longer duration.

[9] Bhutiyani, M.R., Kale, V.S. and Pawar, N.J. (2007). Long-term trends in maximum, minimum and mean annual air temperatures across the Northwestern Himalaya during the twentieth century. Climatic Change, 85 (1-2), pp. 159-177.

[10] Basistha, A., Arya, D.S. and Goel, N.K. (2009). Analysis of historical changes in rainfall in the Indian Himalayas. International Journal of Climatology, 29 (4), 555–572

60. Shekhar et al. (2010) studied the snowfall patterns in the western Himalayan range and revealed a decrease in total seasonal snowfall of 280 cm over the entire western Himalaya between 1988/89 to 2007/08. The snowfall decreased by ~280, 80 and 440 cm over the Pir Panjal, Shamshawari and Greater Himalaya ranges, respectively. The decreasing trend in total seasonal snowfall over the Karakoram range is only ~40 cm.

61. Studies by ICIMOD show a slight increasing trend of snow cover 2000 to 2010 as shown in Figure 28, a longer trend analysis by Himachal Agricultural University Palampur over a longer period shows a decreasing trend as shown in Figure 29. Data by BBMB up to 2003 shows variations in snow fall over twenty years with no significant trend in Figure 30.

Figure 28 Altitude Snow Wise Cover Sutlej Basin (ICIMOD)

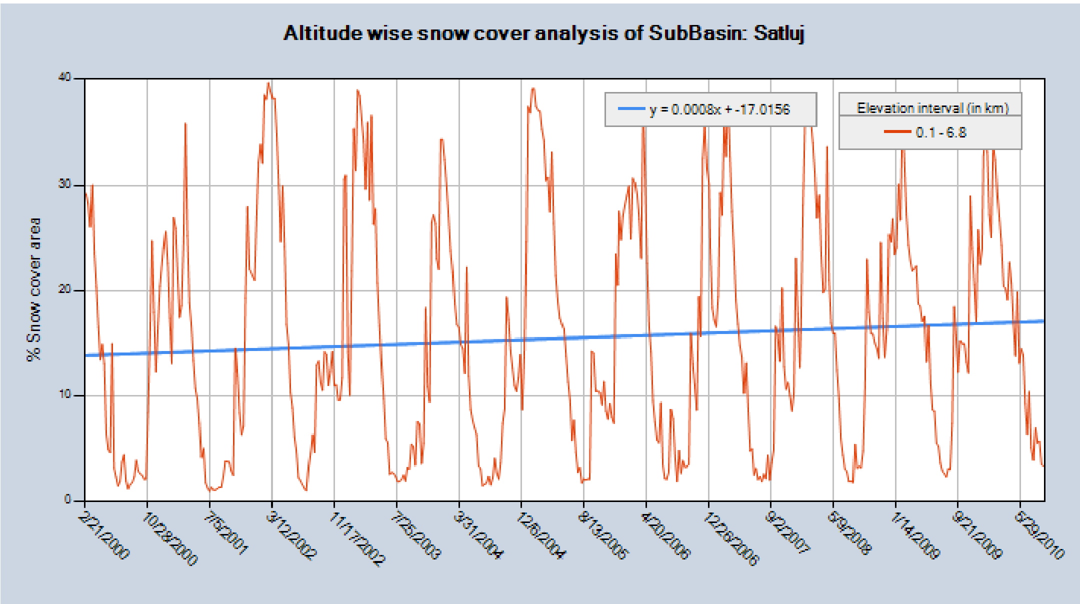


Figure 29 Snow Fall Trends 1985 to 2002

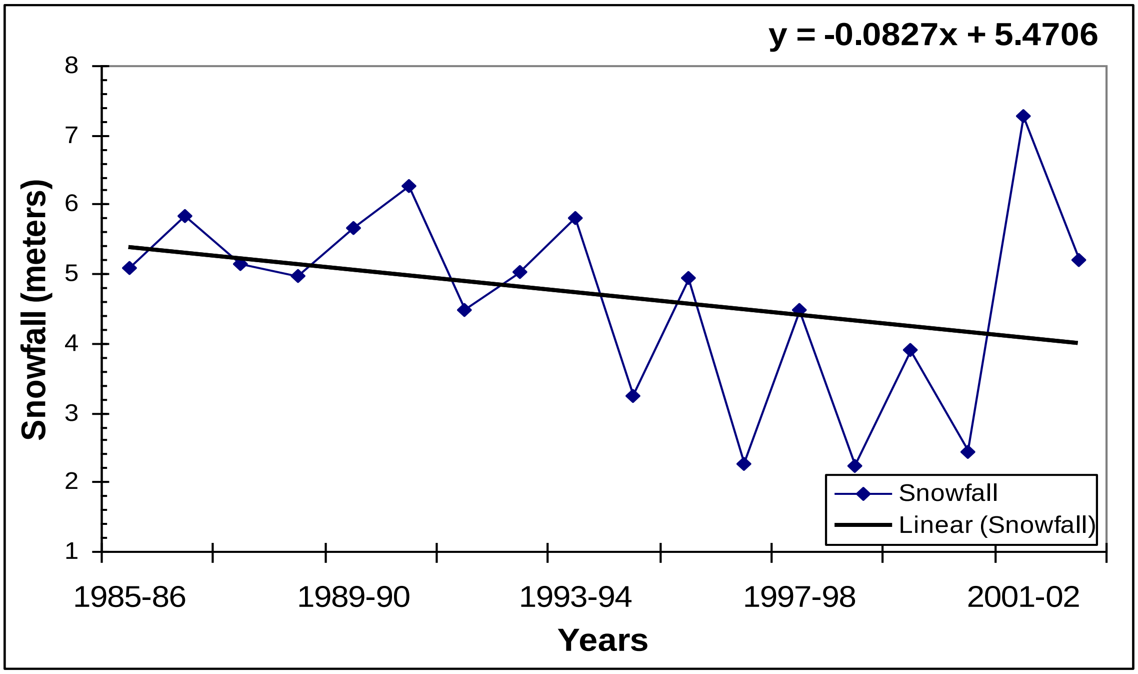
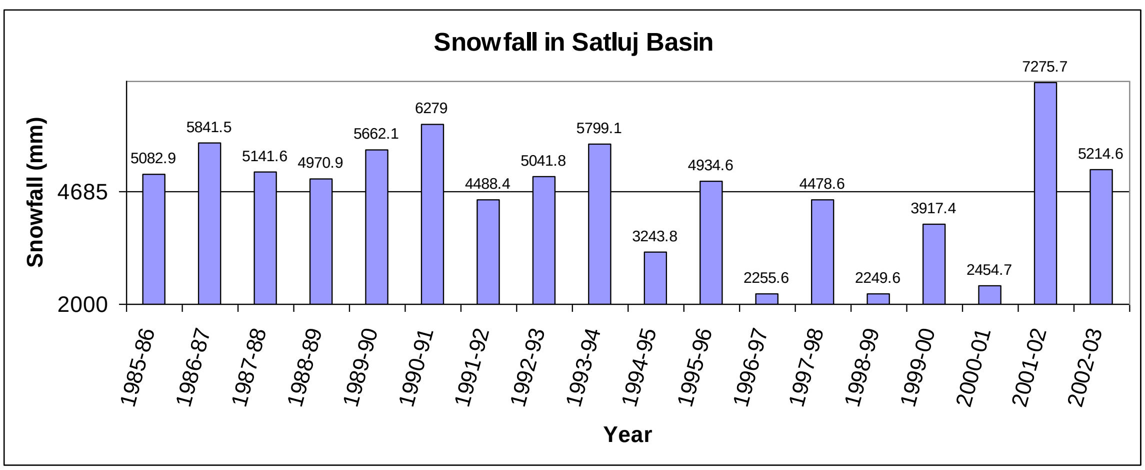


Figure 30 Snow Fall in Sutlej (BBMB)



2. Impact on Hydrology of Himalayan Rivers

62. Daily streamflow and its components (rainfall, snow melt and baseflow) were simulated for a highly snow fed large Himalayan basin (Indian part of River basin, 22,275 km^2) elevation range 500 to 7000 m) has been studied extensively. river receives substantial contributions from rain, snow and glacier melt runoff. About 65% of the basin area is covered with snow during winter, which reduces to about 11% after the ablation period. A conceptual snow melt model which handles both rain and snow was developed. The model is designed primarily for mountainous basins and conceptualises the basin as a number of elevation zones depending upon the topographic relief of the mountainous basin. The ability of the model to simulate snow melt runoff and rainfall runoff separately enabled to estimate the contribution of each component to the seasonal and annual total streamflows. The snow melt and rainfall contributions to the flow varies significantly from the season to season. For two seasons, winter and autumn, rainfall

contribution exceeds the snow melt contribution, while for spring and summer; snowmelt is higher than rainfall contribution. It was observed that most of peaks in the streamflow are generated by the rainfall, but prolonged high flows are generated by the melting of snow. The model was also applied to estimate the contribution from snow melt and rainfall into seasonal and annual flows. The analysis suggests that more than two-third (about 68%) of annual flows is generated from the snow melt runoff. The seasonal distribution of streamflow indicates that about 60% of the annual flows are obtained during summer season and about 75% of this summer flow is obtained from the snow melt (Singh and Jain, 2003). Such estimates are useful for planning and management of schemes in this basin. For the same study area, based on water balance approach for a 10 years period (1986/87-95/96), an average snow and glacier melt contribution in the annual flow of Sutlej river (Indian part) at Bhakra Dam was found to be about 61% (Singh and Jain, 2002)[11]. The modelling approach provides more accurate estimates based on the simulations of total streamflow and its components throughout the study period using modelling approach.

63. Singh and Bengtsson (2003 and 2004)[12] studied the effect of warmer climate on the depletion of snow covered area for the Sutlej River basin. It was found that for the study basin, acceleration in depletion of snow covered area is computed to be 20, 31 and 40 days for T+1, T+2 and T+3°C scenarios, respectively, by the end of ablation season. The impact of warmer climate on accelerating the depletion of snow covered area is found to be higher in the early and late part of ablation season as compared to the mid part of it.

64. In another study, Singh and Bengtsson (2004)[13] investigated the sensitivity of water availability to climate change for Sutlej River basin. After having calibrated a conceptual hydrological model to provide accurate simulations of observed Streamflow, the hydrological response of the basin was simulated using different climatic scenarios over a period of 9 years. Adopted plausible climate scenarios included three temperature scenarios (T+1, T+2, T+3 °C) and four rainfall scenarios (P-10, P-5, P+5 and P+10%). The effect of climate change was studied on snowmelt and rainfall contribution runoff, and total Streamflow. Under warmer climate, a typical feature of the study basin was found to be reduction in melt from the lower part of the basin owing to a reduction in snow covered area and shortening of the summer melting season and, in contrast, an increase in the melt from the glacierized part owing to larger melt and an extended ablation period. Thus, on the basin scale, reduction in melt from the lower part was counteracted by the increase from melt from upper part of the basin, resulting in a decrease in the magnitude of change in annual melt runoff. The impact of climate change was found to be more prominent on seasonal rather than annual water availability. Reduction of water availability during the summer period, which contributes about 60% to the annual flow, may have severe implications on the water resources of the region, because demand of water for irrigation, hydropower and other usage is at its peak at this time.

65. Singh and Bengtsson (2005)[14] studied the impact of warmer climate on melt and evaporation for basin. Following the projected increase in temperature in the Sutlej basin, an estimate of expected changes melt runoff under warmer temperature was made by Singh and Bengtsson (2004, 2005). This study was carried out for three temperature scenarios (T+1, T+2 and T+3°C). This study reveals that under a warmer climate that changes would include:

[1111] Singh, P., and Jain, S. K. (2002). Snow and glacier melt in the Sutlej river at Bhakra Dam in the Western Himalayan region. Hydrological Sciences Journal (47), pp.93-106

[12] ibid

[13] ibid

[14] Singh, P., Haritashya, U.K., Kumar, N. and Singh, Y. (2006). Hydrological characteristics of the Gangotri Glacier, central Himalayas, India. Journal of Hydrology (327), pp.55– 67.

Singh, P., Haritashya, U.K., Ramasastri, K.S. and Kumar, N. (2005). Diurnal variations in discharge and suspended sediment concentration, including runoff-delaying characteristics, of the Gangotri Glacier in the Garhwal Himalayas. Hydrological Processes (19), pp. 1445–1457.

Singh, P., Haritashya, U.K., Ramasastri, K.S. and Kumar, N. (2005). Prevailing weather conditions during summer seasons around Gangotri Glacier. Current Science (88), pp.753-760.

i) **Evaporation** the studies indicated that the increase in evaporation was the maximum for snow fed basins For a T+2°C scenario, the annual evaporation for the rainfed basins increased by about 12%, whereas for the snowfed basins it increased by about 24%. The high increase of the evaporation losses would reduce the runoff. It was found that under a warmer climate, melt was reduced from snow fed basins, but increased from glacier fed basins.

ii) **Melt** from snowfed basin was found to reduce, whereas from the glacierfed basin it increased. Reduction in melt from snowfed basin under warmer climate is possible due to availability of lesser amount of snow in the basin. Results indicate that the effect of warmer climate on the melt from snowfed basin was found to be opposite as compared to the glacierfed basin. Like evaporation, variations in annual melt, either decrease from the snowfed basin or increase from the glacierfed basin, varied linearly with increase in temperature.. For the considered range of temperature increase (1-3°C), the melt from the glaciated basin increased by 16 to 50%, for the snowfed basin snow melt decreased by 11 to 23% for the same increase in temperature. Thus, the magnitude of changes caused by warmer climate was much higher than the snowfed basin.

iii) **Combined effects**: It is important to note that for a complex basin, the decrease in snow melt is counterbalanced by increased melt from the glaciers. For example, in the case of present study, total melt reduced by about 2%, when the whole basin was taken into account. The comparison of the effect of warmer climate on different types of basins. For a T+2°C scenario, annual melt was reduced by about 18% for the studied snowfed basin, while it increased by about 33% for the glacierfed basin. Thus, impact of warmer climate on the melt from the snowfed and glacierfed basins was opposite to each other. The study suggests that out of three types of basins, snowfed basins are more sensitive in terms of reduction in water availability due to a compound effect of increase in evaporation and decrease in melt. The decrease in melt from seasonal snow may be counterbalanced by increase in melt from glaciers.

66. However, in the long-term perspective, glaciers may retreat considerably and their area may reduce, or may even disappear from the basin. The process is, however, beyond the scope of the present study. How the extent of glaciated area will reduce for the Himalayan region is very uncertain and needs more investigations.

67. Rees and Collins (2006)[15] developed and employed a simple temperature-index-based hydro-glaciological model, in which glacier dimensions are allowed to decline through time, with a view to assessing, in data-sparse areas, by how much and when climate warming will reduce Himalayan glacier dimensions and affect downstream river flows. Two glaciers having the same initial geometries were located (one each) in the headwaters of two identical nests of hypothetical catchments, representing contrasting climates in the west and east of the region. The hypothetical catchments were nested such that percentage ice cover declined with increasing basin area. Model parameters were validated against available but limited mass-balance and river flow measurements. The model was applied for 150 years from an arbitrary start date (1990), first with standard-period (1961-1990) climate data and then with application of a 0·06 °C/year transient climatic warming scenario. Under this warming scenario, Himalayan rivers fed by large glaciers descending through considerable elevation range will respond in a broadly similar manner, except that summer snowfall in the east will suppress the rate of initial flow increase, delay peak discharge and postpone eventual disappearance of the ice. Impacts of declining glacier area on river flow will be greater in smaller and more highly glacierized basins in both the west and east, and in the west, where precipitation is scarce, for considerable distances downstream.

---

[15] Rees, H. G.; Collins, D. N. (2006). Regional differences in response of flow in glacier-fed Himalayan rivers to climatic warming. Hydrological Processes, 20 (10), 2157-2169.; Rees, H. G.; Collins, D. N. (2007). An assessment of the potential impacts of climatic warming on glacier-fed river flow in the Himalaya . In: Demuth, S. et al. (eds) (2006) Climate Variability and Change - Hydrological Impacts. Proceedings of the Fifth FRIEND World Conference, Havana, Cuba, November 2006 (IAHS Publ. No. 308), Institute of Hydrology, Wallingford, UK, ISBN: 1901502787, pp. 473-478.

68. Rees and Archer (2006) studied the impact of observed seasonal temperature trend on runoff using derived regression relationships. Decreases of -20% in summer runoff in the rivers Hunza and Shyok are estimated to have resulted from the observed 1°C fall in mean summer temperature since 1961, with even greater reductions in spring months. The observed downward trend in summer temperature and runoff is consistent with the observed thickening and expansion of Karakoram glaciers, in contrast to widespread decay and retreat in the eastern Himalayas. The study suggested that the western Himalayas are showing a different response to global warming than other parts of the globe.

69. A regional hydro-glaciological model was developed by Rees and Collins (2007)[16] to assess the potential impacts of climatic warming on glacier-fed river flows in the Indus and Ganges basins. The model, applied at a 20 km x 20 km grid resolution, considers glaciers contributing runoff to a cell as a single idealized glacier that is allowed to recede through time. Using 1961–1990 climate data as input, 'baseline' flow estimates were derived for every stretch of river in either basin. A transient warming scenario of +0.06°C/year was then imposed for 100 years from an arbitrary start-date of 1991. Comparison of results at 10 sites in two representative areas suggest the impacts of such climatic warming are similar regionally, with estimates of future decadal mean flows continually increasing at 1–4% per decade, relative to baseline, at most sites considered. Flows peaked at only two of the sites several decades into the model run.

70. Singh et al. (2006)[17] studied the impact of warmer climate on glacier melt runoff of Dokriani glacier in Uttarakhand. The results of this indicated that runoff increases linearly with increase in temperature and rainfall. For a temperature rise of 2°C, the increase in summer streamflow is computed to be about 27.9%. Changes in rainfall by ±10% made corresponding changes in Streamflow by ±3.5%. For the considered range of climatic scenarios temperature has greater influence on changes in runoff as compared to rainfall, which possibly is because the study basin has major contribution from snow and glaciers melt runoff. Maximum increase (45%) was computed under T+3°C, P+10% scenario, whereas minimum increase (10%) was under T+1°C, P-10% scenario.

71. Immerzeel et al. (2010)[18] showed that melt water is extremely important in the Indus basin and important for the Brahmaputra basin, but plays only a modest role for the Ganges, Yangtze, and Yellow rivers. They found huge difference between basins in the extent to which climate change is predicted to affect water availability and food security. According to their study, the Brahmaputra and Indus basins are most susceptible to reductions of flow, threatening the food security of an estimated 60 million people.

72. Thayyen and Gergan (2010)[19] presented that Sutlejriver along with all India summer monsoon anomalies (Mall et al., 2006) substantiates this unique river flow response to the glacier change in the Himalayan catchment. An analysis of the runoff data for the Sutlej river from 1920–2004 shows that the highest discharge in the river was observed during 1945–1965 in association with a period of strong monsoon. As a result, many glaciers in the Himalayan region probably experienced a positive mass balance regime and showed signs of advancement or reduced rate of recession or were stationary during

---

[16] ibid

[17] Singh, P., Haritashya, U.K., Kumar, N. and Singh, Y. (2006). Hydrological characteristics of the Gangotri Glacier, central Himalayas, India. Journal of Hydrology (327), pp.55– 67.

Singh, P., Haritashya, U.K., Ramasastri, K.S. and Kumar, N. (2005). Diurnal variations in discharge and suspended sediment concentration, including runoff-delaying characteristics, of the Gangotri Glacier in the Garhwal Himalayas. Hydrological Processes (19), pp. 1445–1457; Singh, P., Haritashya, U.K., Ramasastri, K.S. and Kumar, N. (2005). Prevailing weather conditions during summer seasons around Gangotri Glacier. Current Science (88), pp.753-760; Singh, P., and Jain, S. K. (2002). Snow and glacier melt in the Sutlej river at Bhakra Dam in the Western Himalayan region. Hydrological Sciences Journal (47), pp.93-106; Singh, P., Jain, S. K., Kumar, N., and Singh, U. K. (1993). Snow and glacier contribution in the Ganga river at Devprayag. CS(AR) 132, NIH, Roorkee, 1993-94; Singh, P., Jain, S. K., and Kumar, N. (1997). Estimation of snow and glacier melt runoff contribution in the Chenab River at Akhnoor. Mountain Research Development (17), pp.49-56

[18] Immerzeel W.W, Ludovicus P. H. van Beek, Marc F. P. Bierkens (2010). Climate Change Will Affect the Asian Water Towers. Science (328), pp.1382-1385

[19] ibid

the 1950's to early 1970's (Mayawski et al., 1980; Vohra, 1993; Sharma and Owen,1996; Bhattacharyya et al., 2001)[20]. Since the mid-1960's, runoff in the Sutlej river has decreased compared to the discharge during the mid-1940's and 1950's. Concurrently, this period is also marked by widespread glacier recession in the region (Kulkarni et al., 2007; Thayyen et al., 2007b). The advancement of glaciers reported from the trans- Himalayan region during the 1890–1910 period is also attributed to the strong monsoon during the 1885–1900 period (Mayewski and Jeschke, 1979; Mayewski et al., 1980).

3. Impact on Extreme Flows

73. A major impact of climate change is likely on the frequency and magnitude of extreme flow events. In view of the recent climate change, the assumption of stationarity in the flow records cannot be justified. Design of hydrological systems is, therefore, likely to be more reliable if the impacts of potential climate change on extreme events are considered. Sharif et al. (2010) investigated trends in extreme flow measures for a set of Streamflow gauging stations in Sutlej River Basin in India. Linkages of extreme flow measures with large scale climate indices have also been identified. The analysis includes an exploration of the types of trends that may occur in an extreme flow record, which include changes in the timing of extreme events, and changes in the extreme event magnitudes. Several extreme flow measures including the high flow and low flow magnitudes and their dates of occurrence have been analyzed for the detection of trends using Mann-Kendall non parametric test. The results reveal more trends than would be expected to occur by chance for various measures of extreme flow characteristics. The data has been found to exhibit changes in both the magnitude and the timing of extreme flow events.

4. Retreat of Glaciers

74. Glaciers in the Himalayas have been reported to be retreating since AD 1850 (Mayewski and Jeschke, 1979). Recently Ministry of Environment and Forests reviewed the retreat of glaciers in India (Raina, 2009). Available data on various glaciers on recession of glaciers was compiled and analysed. Data that has been generated from the glacier studies, in the Himalayas, over the last 100 years or so, indicates that the glaciers, in the Himalayas, have been, by and large, shrinking and retreating continuously, barring a flip here and there, but the rate of retreat can not be considered as alarming/ abnormal, especially in the last decade or so. A brief of few selected glaciers is given below:

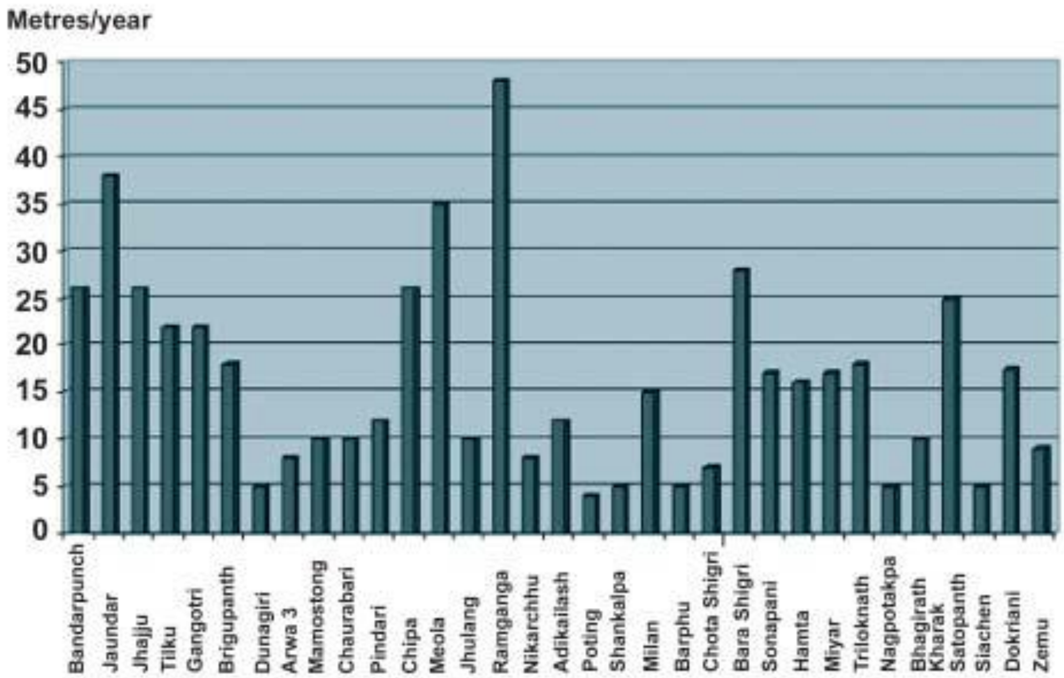
- **Siachen glacier**, the second largest glacier known outside the polar and sub- Polar Regions, is a valley glacier, about 74km long. Snout of this glacier has been under observation, off and on, since 1848 and has not shown any abnormal retreat in the last fifty years.
- **Machoi glacier** is a small transverse glacier, less than 2 km long, situated east of Zoji La, very close to the National Highway that connects Srinagar to Leh in Ladakh. This glacier is probably the only glacier in the Himalayas, which has, practically, a continuous photographic record of the snout (glacier front) since 1875 AD. The glacier does not appear to have undergone any major retreat in the last 50 years.
- **Gangotri glacier** is about 30 km long glacier situated in the Bhagirathi valley of the Uttarakhand, India, and is the largest glacier in the Central Himalayas. Snout of the Gangotri glacier, as is typical of glaciers in the Himalayas, is marked by a prominent ice cave that is renowned under the name of Gaumukh-mouth of the cow from where the Bhagirathi river, one of the main tributaries of the river Ganges, originates. Gangotri glacier, it may be noted, had been showing a rather rapid retreat at an average of around 20m per year till up to 2000 AD, which had led to the imaginative prediction of the end of this glacier in next 35 years or so. In actual fact, since 2001 AD, rate of the retreat has come down considerably and between September 2007 and June 2009 this glacier is practically at stand still.
- **The Dokriani Glacier** is a valley type glacier located in the Garhwal region of the Central Himalayas. The melt stream originating from Dokriani Glacier is known as Din Gad. It follows a narrow valley and meets Bhagirathi river at Bhukki. The elevation of glacier varies from about 3950-5800 m. The length of this glacier is about 5.5 km whereas its width varies from 0.1-2.0 km from snout to accumulation zone. The snout of glacier is situated at an elevation of about 3950 m and covered by huge boulders and debris. Several studies by different research groups have been carried out on this glacier covering melt runoff distribution, sediment delivery and changes in

20

the position of snout. Recession of snout Dokriani Glacier has been observed between 17 m/year between 1962-1995 ((Dobhal et. al. 2004).

75. In general Glaciers, in the Himalayas, although shrinking in volume and constantly showing a retreating front, have not in any way exhibited, especially in recent years, an abnormal annual retreat, of the order that some glaciers in Alaska and Greenland are reported to be showing. Figure 31 shows the average retreat for glaciers which more than 20 years data is available, assessed till the end of 20th century

Figure 31 Annual (average) retreat of some of the glaciers, in the Indian Himalayas



76. Kulkarni et al. (2007)[21] estimated the glacial retreat for 466 glaciers in Chenab, Parbati and Baspa basins from 1962. The investigation has shown an overall reduction in glacier area from 2077 sq. km in 1962 to 1628 sq. km at present, an overall deglaciation of 21%. However, the number of glaciers has increased due to fragmentation. Mean area of glacial extent has reduced from 1.4 to 0.32 sq. km between the 1962 and 2001. In addition, the number of glaciers with higher areal extent has reduced and lower areal extent has increased during the period.. Dr. Kulkarni and associates from Marine and Water Resources Group, Space Applications Centre, Ahmedabad are also working on certain aspects of the effect of climatic variations on snow and glaciers in Himachal Pradesh. They have also made some glacier retreat studies in the Sutlej river basin using IRS PAN stereo data (Kulkarni, 1999) and observed that during the period 1963 -1997, Janapa Glacier retreated by 696 m, Shaune Garang by 923 m, Jorya Garang by 425 m, Naradu Garang by 550 m, Bilare Bange by 90 m, Karu Garang by 800 m and Baspa Bamak retreated by 380 m. In their studies they observed an overall 19 per cent retreat in glaciated area and 23 per cent in glacier volume in last 39 years. Randhawa et al. (2001), using remote sensing techniques, prepared a glacier inventory for the Sutlej and Beas basins in Himachal Pradesh under Himalayan Glacier Inventory program on the scale of 1:50,000. The mapping was done using LISS I satellite data. The study indicated the presence of total 334 glaciers and 1987 snow fields in the entire Sutlej basin covering an area of 2697 sq. km as a whole.

[21] Kulkarni, A.V., Bahuguna, I.M., Rathore, B.P., Singh, S.K., Randhawa, S.S., Sood, R.K., and Dhar, S. (2007). Glacial retreat in Himalaya using Indian Remote Sensing satellite data. Current Science (92), pp. 69-74.

77. Some glaciers in the Baspa basin have been monitored for long term mass balance observation (Kulkarni *et al*., 2004)[22] using accumulation area ratio. Mass balance was estimated during 2001 and 2002 for 19 glaciers in the basin, suggesting overall specific mass balance value of – 90 and – 78 cm, respectively. Their investigation suggested a loss of 0.2347 km^3 of glacial ice in the last two years. The investigation has shown that four glaciers have no accumulation area, as these are located in lower-altitude zones. These glaciers are expected to face terminal retreat due to lack of formation of new ice. This is likely to pose serious problem of availability of water to many villages located in the Baspa basin[23]. Another active research group at Geological Survey of India at Lucknow as a part of their study on “Glacier recession in Himalayas” has shown that Sutlej basin has 926 glaciers covering an area of 1252 km^2. They have also studied the Sutlej basin glaciers Gara, Gor Garang, Shaune Garang, Nagpo Tokpo in details and observed an average retreat of 4.22 -6.8 m/year in all these glaciers. Glacial recession of some glaciers in Himachal Pradesh is summarised in Table 8

Table 8 Glacial Recession in Himachal Pradesh

Name of the Glacier	Period of Observation	No. of Years	Average retreat (m/year)
Gara Glacier	1973-1983	10	6.80
Nagpo Tokpo	1962-1998	36	6.40
Shaune Garang	1981-1991	9	4.22

(Source: Srivatastava, 2003)

5. Glacier Mass Balance

78. Mass balance of any glacier at any time is either positive or negative showing surplus or deficit of ice on the glacier body. Increase in mass of ice is referred to as advancement of glacier, whereas decrease is referred to as retreating of glacier. Specific balance is the net balance per unit area of a glacier and expressed in mm of water equivalent. Annual mass balance measurements of the Dokriani Glacier in Gangotri area of Garhwal Himalaya were conducted by Dobhal et al. (2008) from 1992-93 to 1994-95 and 1997-98 to 1999-2000. The study was carried out by glaciological method, including weekly measurement of ablation stakes and fixed date measurement of net accumulation. Results of annual mass balance for six years show negative trend with the maximum deficit of $-3.19 \times 10^6\ m^3$ water equivalent in 1998-99. Annual mean mass balance from 1992-93 to 1999-2000 was $-2.25 \times 10^6\ m^3$ water equivalent/year. The resulting $13.54 \times 10^6\ m^3$ water equivalent cumulative volume loss, equal to a thickness reduction of 1.94 m over the study period is significant, since the Dokriani Glacier has average ice thickness of 50 to 55m. Substantial wasting by -2.5 to -3.0 m water equivalent/year in the ablation area, compared to the mass gain by 0.45 to 0.55 m w.e./year in the accumulation area was recorded. Equilibrium line altitude (ELA) has ascended from 5030 to 5095 m a.s.l. and accumulation area ratio (AAR) fluctuated between 0.67 and 0.70 during the study period. A summary of mass balance for different Himalayan glaciers is given in Table 9. It is to be noted that all glaciers in the Indian Himalayas have shown negative specific mass balance for the period they were studied.

Table 9 Specific mass balance of few Himalayan glaciers (Shanker and Srivastava, 2001; Dobhal et al., 2008)

S. No.	Glacier	Location	Period of study	Cumulative specific balance (m)
1	Gara Glacier	H.P.	1974-1983	-2.87
2	Gor-Garang Glacier	H.P.	1977-1985	-3.3
3	Shaune-Garang Glacier	H.P.	1981-1990	-2.87

[22] ibid
[23] SUTLEJ RIVER BASIN - A preliminary investigation into the water reserve mapping, assessment of viability of micro/mega hydropower projects and suggesting alternatives Centre for Geo-informatics Research and Training CSK Himachal Pradesh Agricultural University Palampur-176062, H.P. India

4	Nehnar Glacier	J&K	1978-1984	-2.37
5	Changme Khangpu	J&K	1978-1987	-1.86
6	Rulung Glacier	J&K	1979-1981	-0.21
7	Tipra Bamak	U.K.	1981-1988	-1.34
8	Dunagiri Glacier	U.K.	1984-1992	-6.26
9	Chhota Shigri Glacier	U.K.	1986-1989	-0.21
10	Dokriani Glacier	U.K.	1992-2000	-2.5

79. Berthier et al[24] carried out and an assessment between 1999 and 2004, the 915 km2 of glaciers in Spita and Lahual digitized on an ASTER image have experienced significant thinning at low elevations (8 to 10 m below 4400 m) and limited elevation changes at higher elevations (slight thinning of about 2 m). The overall specific mass balance is −0.7 to −0.8 m/a w.e., showing that glaciers of the Spiti/Lahaul region are experiencing rapid ice losses. The volume loss over five years is estimated at 3.9km3 of water. These losses are at least twice higher than the average mass balance between 1977 and 1999 (−0.34 m/a w.e.) for the Himalaya (Dyurgerov & Meier, 2005) indicating an increase in the pace of glacier wastage. For the Spiti part which lies in the Sutlej catchment the glacier area is estimated 650km2 with a loss over 5 years of 2.96km3 of water and with specific mass balance of -0.7 to 0.9m/a w.e

E. Glacier Inventory for Sutlej

80. Two different inventories of glaciers have been sourced; each giving different assessments of the areas and estimated volumes.

1. Geological Survey of India

81. The Geological Survey of India (GSI) has conducted a comprehensive inventory of the Himalayan glaciers. All the glaciers have been coded and the data on the locations and areas derived from aerial photographs and satelllite imagery. The analysis has followed guidelines by UNESCO and guidelines from the world glacier inventory, In the absence of factual information on the depth estimates have been based on information on the alpine and himalayan glaciers in Nepal and applying these to the Sutlej basin. The assessment only covers the Indian part of the Sutlej . The summary of the GSI inventory is given in Table 10

Table 10 Geological Survey of India Glacier Summary

Tributary	Basin Area Km2	Nr Glaciers	Glacierised Area(km2)	Glacierised % of basin	Total Ice Volume (km3)
Kurpan	344	2	0.2	0.1	0.002
Nogri	512	7	0.25	0.1	0.002
Kut	340	11	9.2	2.7	0.270
Soldan	331	3	2.74	0.8	0.080
Sorang Wanger	665	70	99.6	15.0	4.500
Baspa	1100	89	238.7	21.7	15.300
Tirung	916	60	135.4	14.8	6.400
Taiti	885	62	77	8.7	2.850
Tagla Gyamthing	187	27	19.2	10.3	0.580
Ropa	628	48	27.31	4.3	0.710
Hojis Sutlej	309	15	21.32	6.9	0.750
Spiti	7674	532	620.6	8.0	29.520
Total	**13891**	**926**	**1251.52**		**61.0**

[24] Remote Sensing of Glacier Mass Balances in Himachal Pradesh Etienne Berthier et al 2006

2. Himachal Palampur University[25]

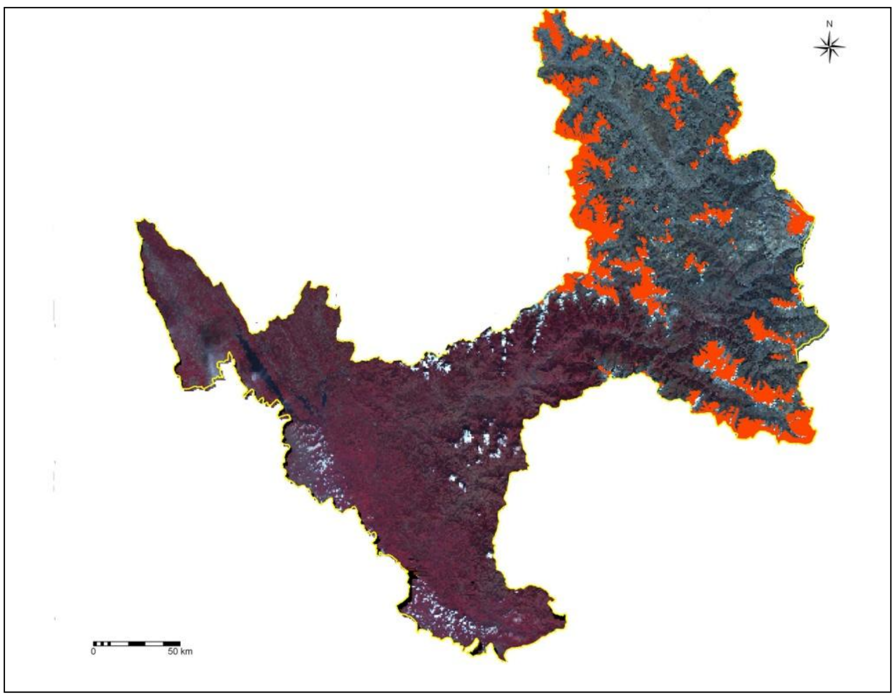
82. An comprehensive inventory and GIS database of glaciers was prepared[26] The inventory of glaciers has been based on topographic maps and satellite images. Glaciers were digitized on the satellite image and the identification, classification, and determination of stages of glaciers was accomplished by r*eferr*ing topographic maps of the glaciated regions of Himachal Pradesh. The spatial inventory is based entirely on topographic maps on a scale of 1:50,000 published in the 1960s to 1970s by the Survey of India. The study assessed the aerial extension of the glaciers is found with the help of geographic information systems (GIS). The area of glaciers are shown in Figure 32.

83. Since the mean glacier thickness data are not available, the study used a formula to estimate the ice reserves based on the area estimated from the equation developed for the Tianshan Mountains (Chaohai Liu and Liangfu 1986). This is a guideline as for the steep U shaped glacier valleys it is not easy to assess the thickness based on the surface area.

- $H = -11.32 + 53.21F^{0.3}$
- Where H = mean ice thickness (m) and F = area of glacier (km^2)
- The ice reserves were estimated by multiplying the mean thickness by the area of the glacier.

84. Eighty percent of the Indian Sutlej river catchment in Himachal was observed to be snow fed. The glaciers were found to be mostly distributed in the north eastern part of the basin. There were 945 glaciers inventoried altogether with a cumulative area of 1217 km2 and an indicative ice reserve of $94km^3$

Figure 32 Glaciers in Sutlej Basin Himachal Pradesh



85. The aspect of the glaciers in the Sutlej basin was randomly distributed in all directions. The glaciers with north, northwest or northeast aspect are generally large in number and aerial extension. They constitute more than 50 per cent in number and cover 69.3 per cent of the area occupied by total glaciers in the basin. The distribution of glaciers in southern aspect covers about 37 per cent of the total number of the glaciers. Eastern and western aspects contain only 5 and 6 per cent of the total number of glaciers.

[25] Himachal Palampur University Centre for GeoInformatics
[26] ibid

As a general rule, the west aspect is much warmer than the east aspect and is expected in the number and area of glaciers, but in the study area i.e.Sutlej basin, not much difference was observed.

3. Comparison of Assessments

86. A comparison of the two assessments is given in Table 11 below. The number of glacier and areas are quite consistent but with some difference in the ice volume .

Table 11 Comparison of Glacier Estimates

Source	Number of glaciers	Area (km2)	Estimated ice volume Km3 for Indian Sutlej	Estimated area for Spiti river (km2)	Estimated icevolume for the Spiti river (km3)
Geological Survey of India	926	1251	61	620	29.5
Palampur University	945	1217	94	524	35.0
Average	935	1234	77	572	32

F. Glacier Lakes

87. Though no major apparent Glacier Lake Outburst Flood (GLOF) event has ever occurred in the state however, quite a few lakes have been identified which may pose danger in the coming future as the glaciers are retreating at an alarming rate due to global warming. It is concluded that even though, the present day risk for an outburst from glacial lakes occurring in Sutlej basin may be low, but the risk of an outburst of glacial Lake in the future could be anticipated high and it might occur in coming 15–20 years, considering the present trend of climate change (Häuslar and Leber (2000). It is proposed that besides making a temporal inventory, a close monitoring of these lakes is required to assess the change in their behaviour. This will help in strengthening database and also help in undertaking an appropriate pre disaster mitigation measure and in avoiding flash flood tragedies common in the hilly region.

88. Himachal Pradesh In 2004, the CSK Himachal Pradesh Agricultural University (CSKHPAU) collaborated with ICIMOD to prepare an inventory of glaciers and glacial lakes in the Himachal Pradesh (HP) Himalayas. The study identified 2,554 glaciers with a total area of 4,161 sq.km. Using remote sensing techniques, 156 glacial lakes were identified with a total area of 385 sq.km, of which 16 were considered potentially dangerous The characteristic features used to identify potentially dangerous lakes in general are:

- moraine-dammed glacial lakes in contact or very near to large glaciers,
- merging of supra-glacial lakes at the glacier tongue.
- some new lakes of considerable size formed at glacier tongues,
- lakes rapidly growing in size, and
- rejuvenation of lakes after a past glacial lake outburst event.

89. A summary of the major lakes and most dangerous lakes as assessed by Palampur Agricultural University are shown in Table 12 below. The study assesses three as potentially dangerous.

Table 12 Major Glacier Lakes in the Sutlej

SN	Lake Type	Lake Number	Area (sq m)	Associated Glacier	Distance to Glacier	Remark	Dangerous lakes
1	Valley	Sutlej_gl 1	41626	None	-	Away from the glacier, situated in the main course of the river	
2	Morraine	Sutlej_gl 7	27779	Sutlej_gr 116	571	Formed due to retreat	Dangerous

SN	Lake Type	Lake Number	Area (sq m)	Associated Glacier	Distance to Glacier	Remark	Dangerous lakes
	dammed					of glacier and chances of expansion	
3	Morrained ammed	Sutlej_gl 9	30981		-	Not in the main Streamflow so less chances of expansion	
4	Morraine dammed	Sutlej_gl 10	58659	Sutlej_gr 183	139	Formed due to retreat of glacier and chances of growing the lake	Dangerous
5	Morraine dammed	Sutlej_gl 13	34504	Sutlej_gr 692	69	Close to the hanging glacier	Dangerous
6	Erosion	Sutlej_gl 18	52706	Sutlej_gr 739	0	Mother glacier is very small	
7	Morraine dammed	Sutlej_gl 25	29427	Sutlej_gr 749	0	Isolated from the glacier due to retreat	
8	Morraine dammed	Sutlej_gl 26	22800	Sutlej_gr 756	59	Glacier channel is narrow and less chances of ice avalanche	
9	Morraine dammed	Sutlej_gl 29	28862	Sutlej_gr 769	920	Away from the main channel and glacier	
10	Morraine dammed	Sutlej_gl 34	44870	Sutlej_gr 865	152	Isolated from the glacier due to retreat	
11	Valley	Sutlej_gl 37	24081	Sutlej_gr 936	3016	Away from the glacier	
12	Erosion	Sutlej_gl 38	28200	None	-	Isolated from the glacier due to retreat	
13	Erosion	Sutlej_gl 39	32874	None	-	Isolated from the glacier due to retreat	
14	Valley	Sutlej_gl 40	135794 075	None	-	Artificial lake	

III. GROUNDWATER

A. Introduction

90. The basin area lies between 76^{o} 22$^{'}$E & 78 ^{o} 42' E longitude and 31 ^{o} 13'N to 32 ^{o} 23'N latitude. Elevation of catchment ranges from 500 to 700 m (amsl), the average being 360m. During winter, the snow line in the basin descends to about 2000 m. Sutlej river enters Punjab near Nangal & moves down to plain area at Ropar, passes through Ludhiana and joins Beas river at Harki. The Lower Sutlej basin is irrigated by Bist-Doab and Sirhind irrigation system. Sirhind canal system is of 59.44 km length and its capacity is 12622 cusecs. The canal irrigated area is 29% and ground water irrigated area is 71%. The north and central part of Lower Sutlej Basin is an area of increased ground water over–exploitation. It has caused depletion in dynamic ground water resource & decrease in levels of ground water beyond economic lift. The south western part of state is water logged and affected by salinity. Besides this, problems of high levels of fluoride, selenium and arsenic in ground water have been reported in lower Sutlej basin. Major part of the basin experiences ground water overexploited condition, thereby indicating a negative balance when withdrawal exceeds the replenishable groundwater recharge. The groundwater situation is summarised in Table 13 below.

Table 13 Groundwater Situation in Punjab

Annual Ground Water Availability	21.44 BCM
Ground Water Extraction	31.16 BCM
Average level of ground water development:	145%
Very high level of ground water extraction in Districts of Fategarh Sahib, Amritsar, Jullandhar, Kapurthala, Ludhiana, Mansa, Moga, Nawanshar, Patiala and Sangrur	144 to 254%
Ground water over-exploited blocks(no)	103 out of 137
Critical blocks	5
Ground Water Over exploited block in 1984	64 nos.
Ground Water Over exploited block in 2006-07	103 nos.
Decline in level of ground water	4.5 to 13.5 m
Area identified for recharging ground water In the basin by CGWB	16450 Km^2
Water logged Area	200,000ha
Salinity affected area	1 000 000ha

B. Aquifers

91. In Lower Sutlej basin, ground water occurs in multi-layered alluvial aquifer system which mainly comprises unconsolidated permeable sand, silt and gravel layers. A moderate thickness of aquifer exists up to 300m. The shallow ground water occurs under unconfined and deeper under semi-confined conditions. The hydro geological map of the district is given in Figure 33. The sub-surface geological fence diagram depicting extent and thickness of aquifer system is shown in Figure 34 . The aquifers in Lower Sutlej basin are extensive and productive. The tubewells located in the depth levels of 50 to 250 m are capable of yielding 1000 to 3500 litre per minute. Hydro geological characteristics of aquifer (zone wise) are given in Table 23.

1. Ground Water Level Trend and Flow

92. The shallow ground water levels of less than 5 m below ground level occur in south western part of the Basin. In the north-central part, the ground water levels are in the range of 10 to 15 m. Deeper levels of 20 to 40 m below land surface occur in the districts of Mogha, Ludhiana and Patiala. The northern and eastern part of the Basin has ground water level depth ranging from 5 to 10 m. Depth to ground water level is lowest (1.12 m) in Muktsar and highest (33.50 m) in Ludhiana district, the former being water logged and saline and latter as over-exploited area. A map indicating water-logged and saline areas in Punjab state is provided in Figure 42.

93. Ground water in the unconfined aquifers move from area of high head in northeast to areas of low-head in the west and southwest. The location of the ground water observation wells monitored by CGWB is given at Figure 35. The depth to ground water level maps for pre and post monsoon period for the basin is given at Figure 36 and Figure 37 respectively. The ground water table map of the area is given at Figure 38. . The hydraulic gradient of unconfined aquifer system is large in the north-east, moderate in central, western and southern parts. Both annual and long-term fluctuations in the level of ground water occur in 11 out of 19 districts of the state.

2. Groundwater level Decline / Rise

94. Indiscriminate development and use of groundwater through wells and tubewells have caused a steep decline in level of groundwater. The position of declining trend in water table due to groundwater over abstraction is depicted for observation well hydrographs (maintained by CGWB) given in Figure 39. Similarly due to excessive irrigation is south western district of state a situation of rising trend leading to waterlogged situation has been created. This is substantiated through CGWB well hydrograph data from Muktsar districts. The depth to groundwater table in pre-monsoon & post monsoon periods, the altitude of groundwater table and gradient for North-East, North–Central and south western parts are tabulated in Table 14 below:

Table 14 Groundwater Level Depth and Trend

Zones	District	Ground water Depth (metre below ground Level)		Trend (Decline in m/yr)	Nature of Aquifer	Water table Altitude (m a msl) / Hydraulic Gradient (m/Km)	Water Quality Type
		Pre-monsoon	Post monsoon				
Zone I – North Eastern Area	Hoshiarpur Nawanshahar Ropar Fatehgarh sahib Patiala	4.00-11.52 8.80-29.70 2.70- 10.30 7.65 – 27.20 6.99- 24.28	2.65-17.05 8.80- 23.70 2.10-11.60 7.02- 30.06 4.43- 20.62	0.68-0.07 0.025-0.56 0.50	Sand ,gravel Sand ,gravel Sand ,gravel Sand ,gravel Sand	230 – 300 /1.05	Ca-HCO3
Zone II. North-central Area	Jalandher Ludhiana Kapurthala Mogha Mansa Sangrur	6.00-29.00 9.24-25.48 4.48-22.93 7.62- 30.49 3.89- 12.36 8.72- 23.89	 5.09-33.62 3.78-24.60 8.00-32.00 9.95-25.41	 0.11-1.34 0.20-1.00 0.20- 1.00 0.65	Sand ,gravel Sand ,gravel Sand ,gravel Sand ,gravel Sand ,kankar Sand ,gravel	198-212 / 1.08	Ca-Hco3 Ca,Mg – Hco3 Ca-Hco3 Ca-Mg Hco3
Zone III - South – western Area	Faridkot Ferozpur Muktsar Bhatinda	2.80-14.60 1.60-11.07 2.00-5.00	1.85- 15.40 0.75-10.57		Sand , silt -clay Sand clay Sand.silt	155-203	

3. Mean Ground Water Level Depth

95. The mean ground water level data for pre and post monsoon periods is given in Table 15 below.

Table 15 Mean ground water level in Lower Sutlej Basin.

Sl No	District	Mean GW Depth (m bgl)			
		May-80	**Nov-80**	**May-09**	**Nov-09**
1	Rupnagar	6.79	6.24	7.59	6.35
2	Fateh Garh	5.30	3.89	17.56	16.82
3	Nawanshahr	11.74	11.08	21.32	21.85
4	Hoshiarpur	7.15	5.83	11.80	8.65
5	Jalandhar	8.48	7.74	19.32	19.58
6	Ludhiana	8.13	7.73	17.02	18.43
7	Kapurthala	4.64	4.15	12.03	13.35
8	Moga	1.32	0.90	17.16	18.64
9	Sangrur	5.90	5.90	21.18	22.14
10	Patiala	7.03	5.65	15.03	13.47
11	Mansa	9.93	9.59	9.40	9.90
12	Bathinda	12.02	9.23	10.69	11.03
13	Firozpur	10.01	9.49	4.82	4.80
14	Muktsar	13.33	10.31	2.31	2.60
15	Amritsar	5.78	7.19	13.97	14.08
16	Faridkot	7.35	2.73	7.16	7.16
17	Gurdaspur	7.09	5.95	7.63	6.51

C. Water Quality

96. The most common groundwater quality problems in the lower Sutlej sub basin are largely caused by natural constituents but exacerbated by human activity. These are high salinity, high levels of fluoride, and high levels of chloride and nitrate in shallow unconfined groundwater of the basin .The salinity levels in groundwater increase from north –east to south –west in the basin. Groundwater in south-western districts have moderate to high levels of salinity in ground water. The central parts of the state have moderate salinity levels and north-east zone have low salinity in ground water. The ground water salinity map of the basin with contours of Electrical Conductivity is given in Figure 40. The block wise presence of high levels of fluoride , iron, total dissolved solid (EC-Value) chloride and nitrate in the unconfined aquifers as observed by CGWB are given in following tables: An assessment of fluoride levels by district is given in Table 16 and Nitrates in Table 17.

Table 16 High Levels of fluoride is various blocks of Lower Sutlej, Sub-Basin, and Punjab

District	No. of Blocks	No.of Locations	Fluoride range (mg/l)
Firozpur	3	5	1.63-3.4
Fatehgarh Sahib	1	1	1.54
Mansa	4	8	1.58-8.3
Mogha	1	1	1.96
Muktser	1	1	5.36
Patiala	2	2	2.05-2.80
Sangrur	3	6	1.71-11.30

Table 17 High levels of Nitrate in Ground water of Lower Sutlej Sub- Basin

District	No. of Blocks	N. of Locations	Nitrate level (mg/l)	Iron trend No. of Blocks	No of locations	Iron (mg/l)
Bhatinda	5	12	61-401	5	11	1.02-1.61

Fardhoke	2	5	60-287	1	1	1.86-3.10
Firozpur	3	6	69-241	--	--	--
Ludhiana	2	5	57-105	--	--	--
Mama	3	5	70-206	2	3	1.76-1.82
Muktsar	2	6	83-940	--	--	--
Patiala	2	3	47-52	--	--	--
Sangurar	2	3	107-1180	5	7	1.07-1.37

D. Groundwater Resource

97. Groundwater is abundant in quaternary alluvial aquifer along river and in canal irrigated areas where infiltration of surface water, canal seepage and return seepage from applied irrigation is high. The CGWB have estimated the replenishable groundwater resource of the state at 23.78 BCM and net groundwater availability after allowing for natural discharge during monsoon, at 21.44 bcm. The problem of ground water resources in various blocks of the basin is given in Table 24. The estimated annual groundwater draft from irrigation alone is estimated at 30.34 BCM. Deeper aquifers to 450 m depth are capable of sustaining heavy duty tubewells with yield of 1000 to 3000 litres per minutes.

E. Artificial Recharge

98. The study of CGWB (ref. Master Plan for Artificial Recharge to groundwater) has identified an area of 16450 sq km, as groundwater over-exploited in north–central part of the basin as favourable to recharge. The feasible area is depicted in map placed at Figure 41.. As per estimates the aquifers have a potential for sub-surface storage of 12,702 MCM of groundwater through approximately 9793 water harvesting and recharging structures including wells, gabions and check dams. A proposal for management of declining ground water resources and to sustain food production in Punjab State is given in Table 25.

F. Ground Water Irrigation

99. The percent area under irrigation by ground water in Punjab and the basin ranges from 7% in Muktsar district to 100% in Fatehgarh Saheb, the average being 80 to 90 %. District wise area under irrigation by comparison between canal / tubewells is given in Table 18 below. The irrigation potential is shown.

Table 18 Ground Water and Canal Irrigation

Sl. No	District	Percent of ground water Irrigation	% canal Irrigated area
1	Moga	40	60
2	Patiala	3	97
3	Fatehgarh Saheb	2	98
4	Sagarur	32	68
5	Ludhiana	3	97
6	Kapurthala	11	89
7	Jallandhar	3	97

100. The net area irrigated by tubewells increased from 1591 thousand hectare in 1970-71 to 3017 thousand hectare in 2001. The Irrigation potential created and utilized in Punjab state is given in Table 19 below.

Table 19 Irrigation Potential Created and Utilised in Punjab

(000' ha)

State	Potential Created	Potential Utilized	Percentage
Ground Water	6287.15	5747.12	91.42
Surface Water	17.99	16.11	92.33

1. Government Tubewells / Private sector tubewells

101. The district wise number of shallow and deep tubewells and open wells for the lower Sutlej basin is given in Table 20 below. Areas of Drip and Sprinkler are given in Table 21

Table 20: Status of Government /Private Tubewells

Sl.no	District	Shallow TW			Deep TW			Open Wells
		Govt.	Private	Total	Govt.	Private	Total	
1	Bhatinda	3	43370	43373	--	--	0	96
2	Faridkot	2	28554	28556	--	--	0	
3	Ferozpur	26	91636	91662	--	--	0	
4	Hosiarpur	9	69870	69879	276	1561	1837	622
5	FategarhSaheb	83	32318	32401	--	--	0	69
6	Ropar	40	30118	30158	281	612	893	1748
7	NawanShahar	21	27970	27991	89	358	447	--
8	Patiala	35	80463	80498	16	2189	2205	--
9	Sangrur	29	127427	127456	29	2129	2158	278
10	Jalandhar	16	69066	69082	--	--	0	--
11	Kapurthala	33	48693	48726	14	--	14	--
12	Ludhiana	164	108703	108867	108	223	331	92
13	Mansa	4	41969	41973	--	--	0	--
14	Mogha	6	53635	53641	--	101	101	10
15	Muktsar	1	27217	27218	--	--	0	--

Table 21 Areas of Drip and Sprinkler Irrigation

Sl.no	District	Shallow TW		Deep TW		Dug Well	
		Sprinkler	Drip	Sprinkler	Drip	Sprinkler	Drip
	Bhatinda	86	181	--	--	--	--
	Faridkot	77	176	--	--	--	--
	Ferozpur	193	403	--	--	--	--
	Hoshiyarpur	152	303	46	13		3
	Fategarh Sahib	80	166	--	--	--	--
	Ropar	226	344	16	10	10	14
	NawanShahar	60	100	7	1	--	--
	Patiala	260	296	9	30	--	--
	Sangrur	166	285	3	11	1	1
	Jalandhar	161	171	--	--	--	--
	Kapurthala	141	233	--	--	--	--
	Ludhiana	332	553	6	0		
	Mansa	99	472	--	--	--	--
	Mogha	135	208	--	--	--	--
	Muktsar	24	69	--	--	--	--
	Total	2192	3960	87	65	11	18

2. Power for Tubewells

102. The power in Punjab is highly subsidized. Agriculture consumers are free to run the electrical pump sets to draw ground water. Punjab has however passed the preservation of the sub-soil water ordinance 2008 to institutionalize delayed sowing of paddy. The status of electricity usage for tubewells is given in Table 22 below:

Table 22 Numbers of Electrical and Diesel Pumps used for Tubewells by District.

Sr.no	District	Shallow TW			Deep TW		
		Electrical Pumps	Diesel Pumps	Total	Electrical Pumps	Diesel Pumps	Total
1	Bhatinda	26597	41219	67816	4961	592	5553
2	Barnala	7258	760	8018	25325	1098	26423
3	Ferozpur	68184	14447	82631	13596	42	13638
4	Hoshiyarpur	19993	17777	37770	19290	1385	20675
5	Fategarh Sahib	33444	1938	35382	421	11	432
6	Ropar	16212	8309	24521	562	77	639
7	NawanShahar	12040	4998	17038	8529	724	9253
8	Patiala	69639	1313	70952	9034	48	9082
9	Sangrur	3726	442	4168	97282	4078	101360
10	Jalandhar	4197	112	4309	30111	208	30319
11	Kapurthala	45429	6151	51580	2371	213	2584
12	Ludhiana	73402	17798	91200	27517	804	28321
13	Mansa	22598	17487	40085	3735	860	4595
14	Mogha	21720	633	22353	41712	166	41878
15	Muktsar	12077	16830	28907	27	193	220
16	Tarantaran	47811	521	48332	11247	1	11248

3. Regulatory Framework

103. The Government of India published the groundwater Model Bill which was circulated to all states. The State Government of Punjab have considered the matter indicating that legalization of groundwater needs deliberations with stakeholders and that constitutional process and socio-economic implications are to be kept in mind to avoid any unrest is an agricultural based society. The Government of Punjab have however, issued advisory on plantation of paddy before 16th June of the calendar year to help reduce over-exploitation of groundwater.

104. The department of local government of the State of Punjab has amended and notified building by-laws and have made "Rain water Harvesting" mandatory in all new buildings above 200 sq.yards. Bye Laws have been published by MCL of Ludhiana and Jalandhar to make rain water harvesting mandatory in new buildings.

105. The CGWA) have notified Ludhiana city block , Moga I & II blocks, Ahmadgarh mahal Kalan and Sangrur blocks of Sangrur district for regulation of groundwater development. Punjab state has imposed ban on sinking of tubewells in 300 villages on 14th July 2010.

4. Ongoing Programs

106. Water resources programs are in progress include (i) irrigation, flood control and command Area Development Program; (ii) farmers participatory action research program through institutions; (iii) pilot schemes on artificial recharge to ground water. (iv) watershed development program; (v) reclamation of the waterlogged areas; (v) CGWA ground water management and regulation by CGWA (vi) Water conservation component under NREGS

107. **Groundwater Problems and Issues** include (i) availability of abundant groundwater resource which has caused almost a change to paddy and wheat cropping; (ii) over exploitation of groundwater and falling water table (iii) implication for sustainability and cost of extraction; (iv) excessive canal irrigation and lack of drainage in parts with implication of reclamation of water logged and saline areas; and (vi) problems of of selenium in groundwater of Nawanshahar district, Chromium & nickel in

Ludhiana and of fluoride in Amritsar, Faridkot, Ferozpur, Bhatinda, Mansa, Muktsar and Sangrur districts as well as problem of Arsenic in groundwater in south –western part of the basin. Presence of heavy metals in groundwater is reported in the districts of Ludhiana and Fategarh Saheb.

Figure 33 Hydro geological Map

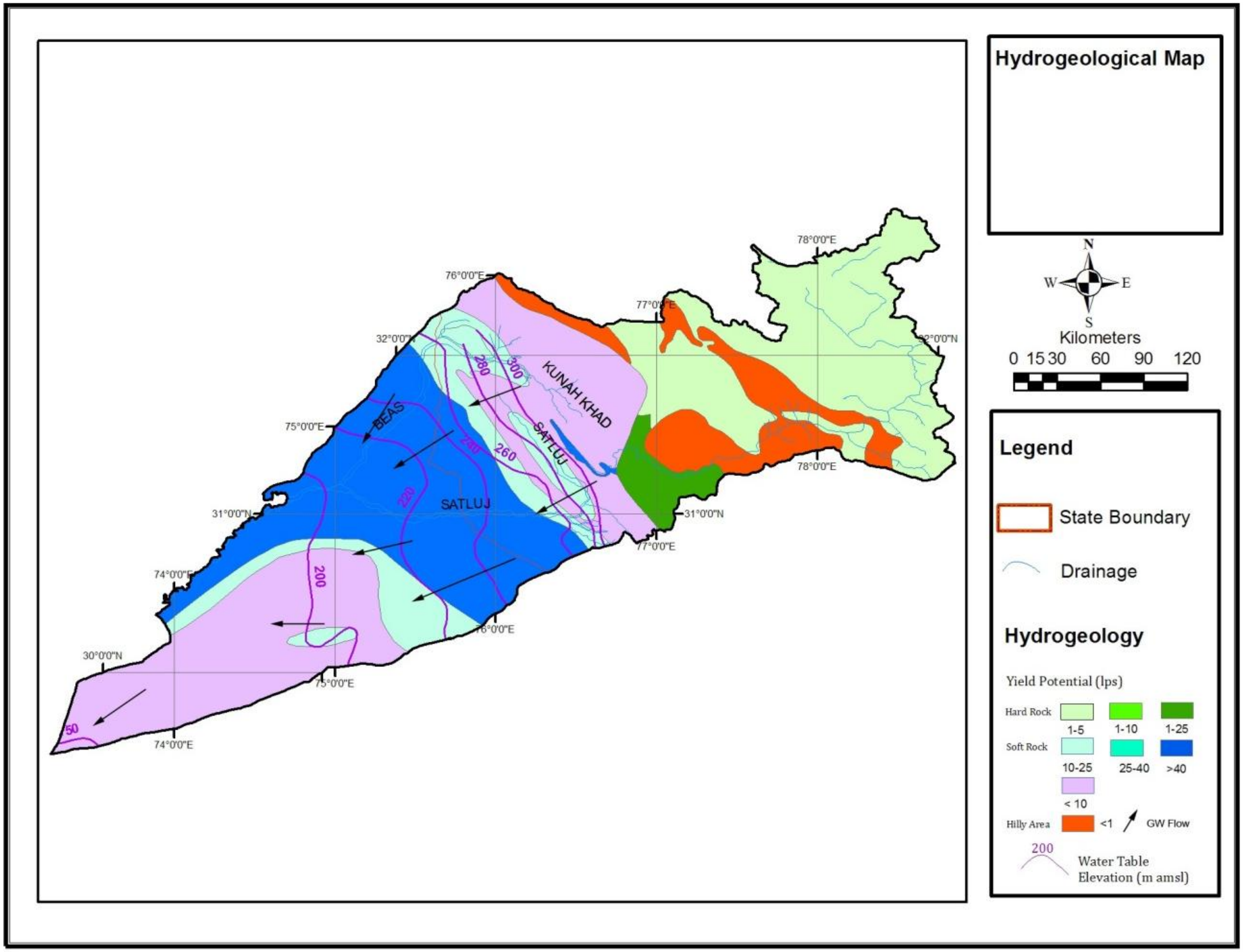


Figure 34 Groundwater Fence Diagram

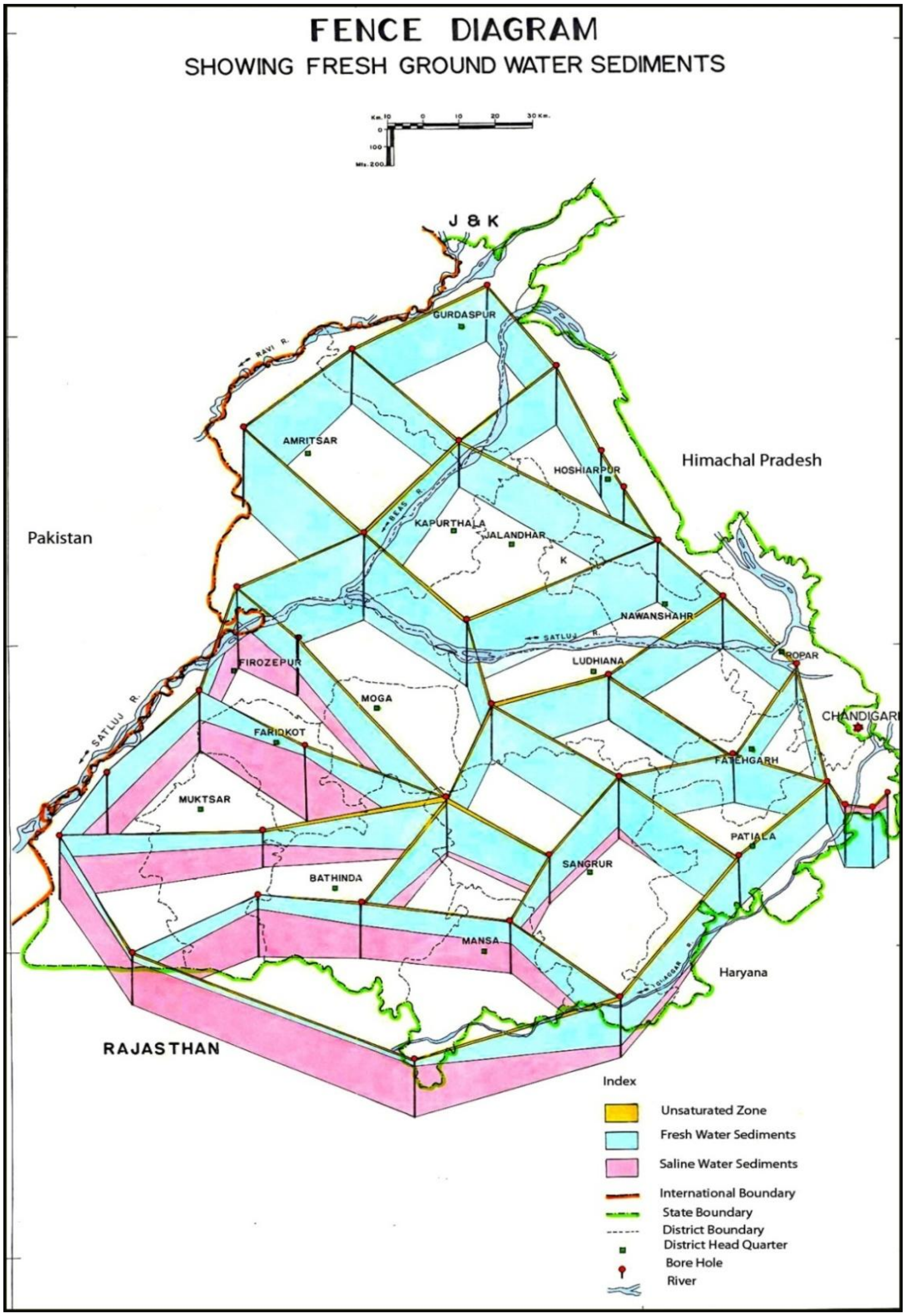


Table 23 Aquifer Characteristics

Zone I : North Eastern Districts	Aquifer Depth (m)	Aquifer Layers (range in m)	Type of Aquifer	Yield (lpm)	Hydraulic Conductivity (m/day)	Transmissivity (m^2/day)	Storativity
Hoshiarpur	4565	0-55 160-225 384-425	Unconfined	700-2900	2-29	634-1120	$58x10^{-2}$ to $1.8x10^{-3}$
Nawanshar	100-450	50-60 50-150	Semi confined	1500-5700	7-53	645-4120	$1.8X10^{-3}$
Ropar	50-460	10-75 50-460	Unconfined	700-1500		123-1180	$7.8X10^{-4}$ $1.7X10^{-3}$
Fategarh	550	10-15 15-50 70-100 150-500	Unconfined Unconfined Semi-confined confined	1600-2500	3-21.6	1790	$1.26X10^{-3}$
Patiala	50-300	0-50 50-250	Unconfined Unconfined Semi-confined/ confined	1000-1280		154-9410	$1.95X10^{-3}$ - $4.7X10^{-3}$
II North-Central							
Kapurthala	300	20 -55 75 - 300	Unconfined Semi-confined/ confirmed	250-3000	-	1739	0.525
Ludhiana	400	10 – 30 50 – 120 150 - 400	Unconfined Semi-confined confined	180-3000		628-1120	$4.3 X10^{-4}$ - $6.98 X10^{-4}$
Jallandhar	300	40 - 130	Unconfined Semi-confined	600-2000	-		$1.95X10^{-3}$ - $4.7X10^{-3}$
Mogha	150	0 – 80 100 - 125	Unconfined Semi-confined	-	-		
Sangrur / Mansa	80 -500	50 – 150 150 - 500	Unconfined / Semi-confined confined	1300 - 2500	-	1020 - 1670	$3.24 X10^{-4}$ - $7.5 X10^{-2}$
III South Western Zone							
Bhatinda	450	40 – 60 50 – 250 250 - 400	Unconfined Semi-confirmed confined	100-1250	-	2724	$2.6 X10^{-2}$
Firozepur	450	10 – 30 40 – 70 100 - 150	Unconfined Semi-confined confined	-	-	327-2600	$0.64 X10^{-3}$ - $27 X10^{-3}$
Muktasar	300 - 400	20 – 50 100 – 300	Unconfined / Semi-confined confined	-	34.78	-	$3.13 X10^{-2}$

Figure 35 Location of Monitoring Wells

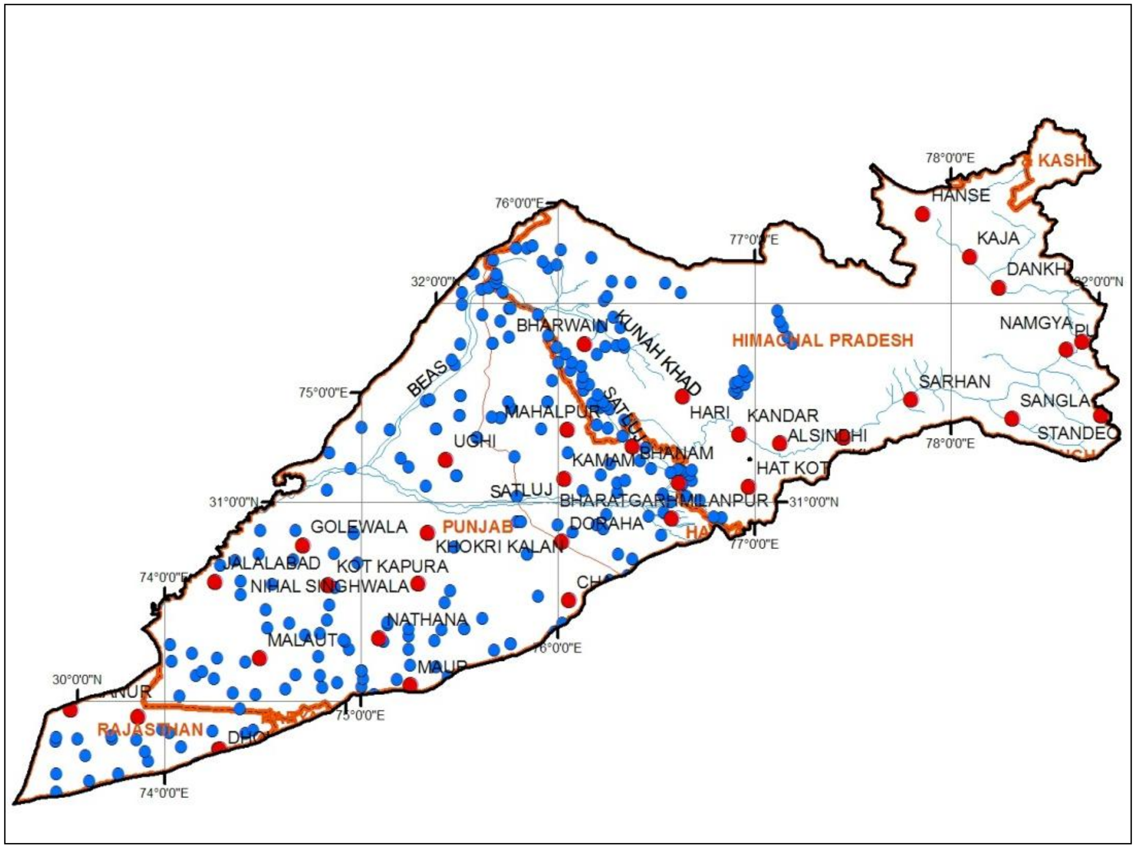


Figure 36 Pre Monsoon Depth to Water Table

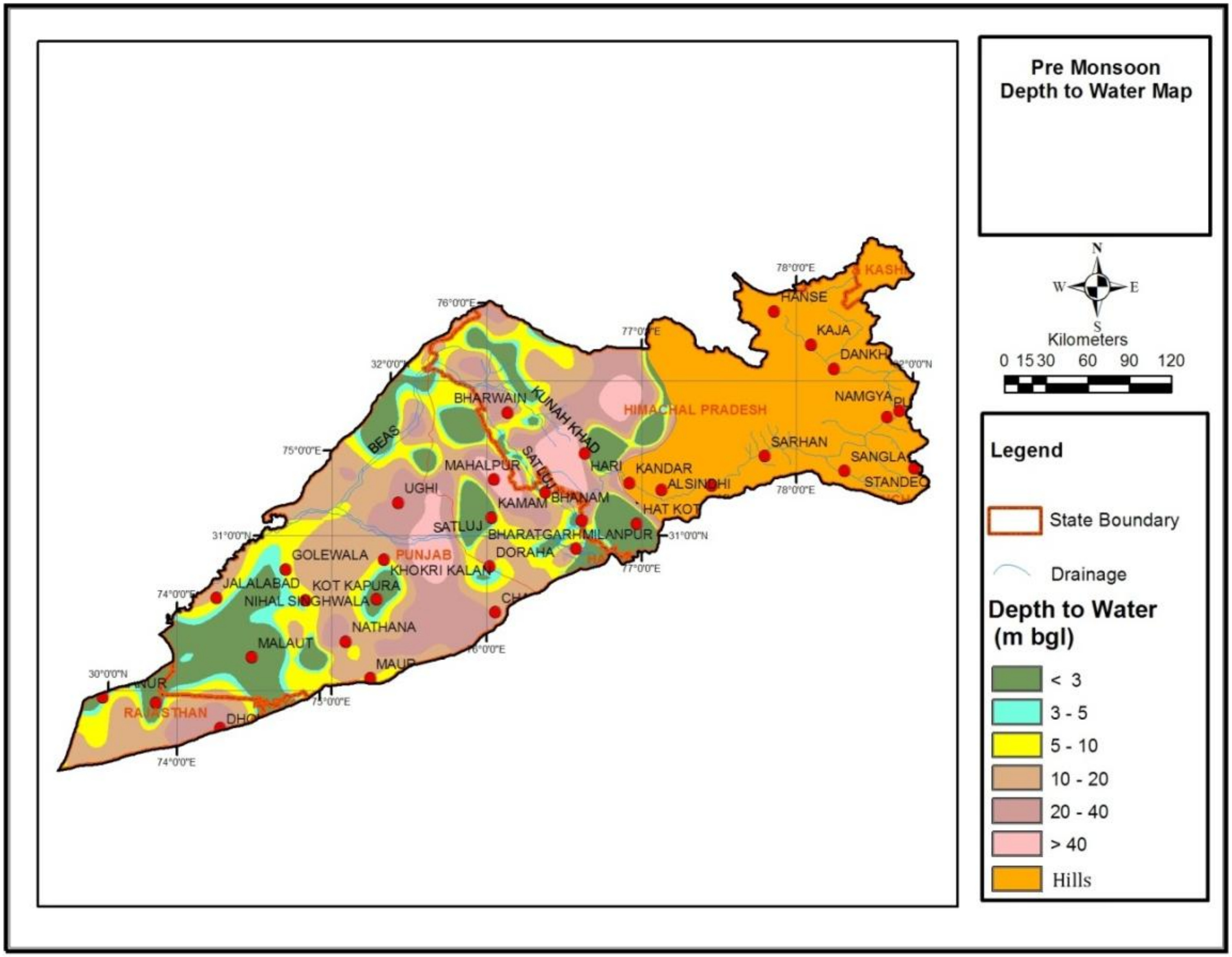


Figure 37 Post Monsoon Depth to Groundwater

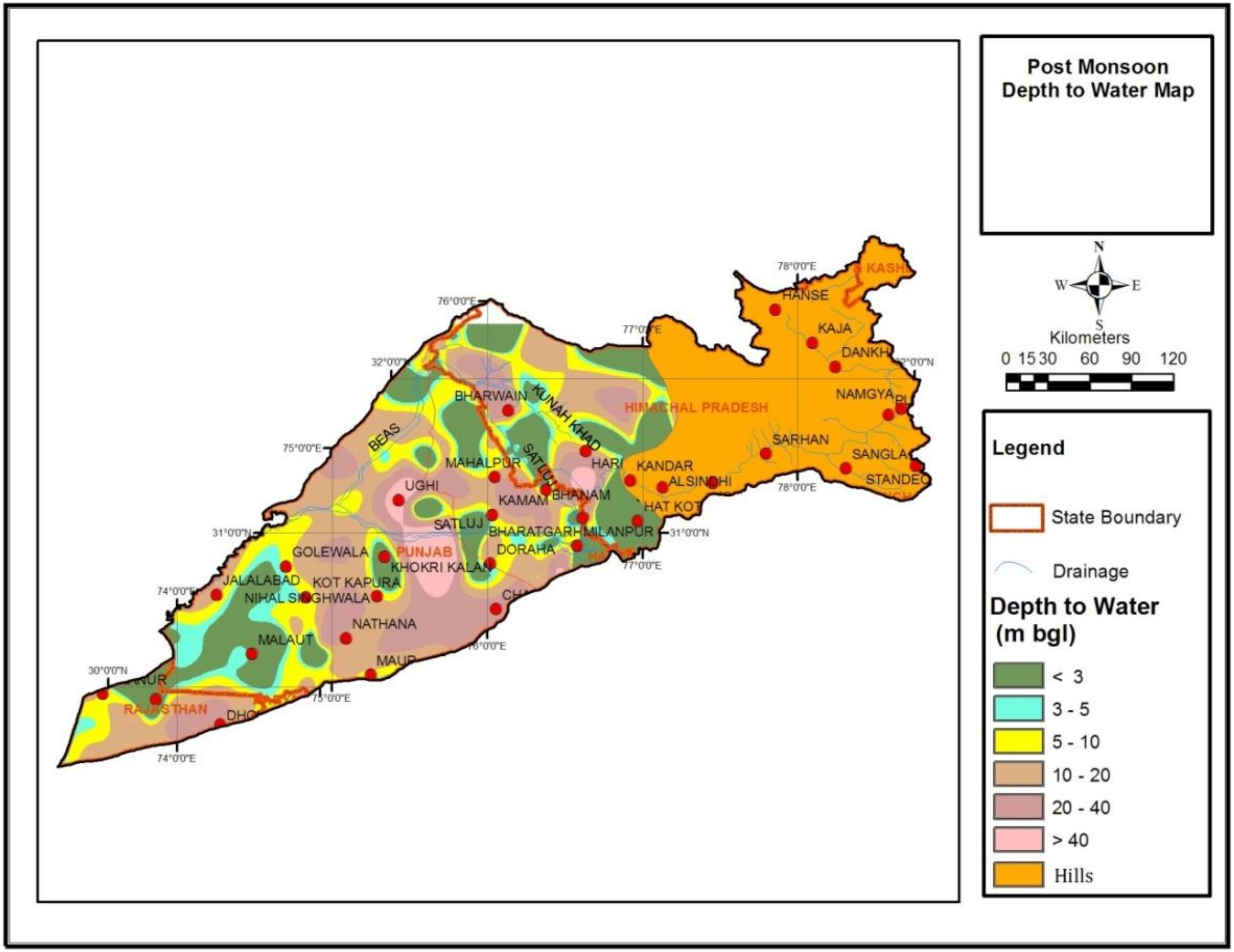


Figure 38 Water Table Map

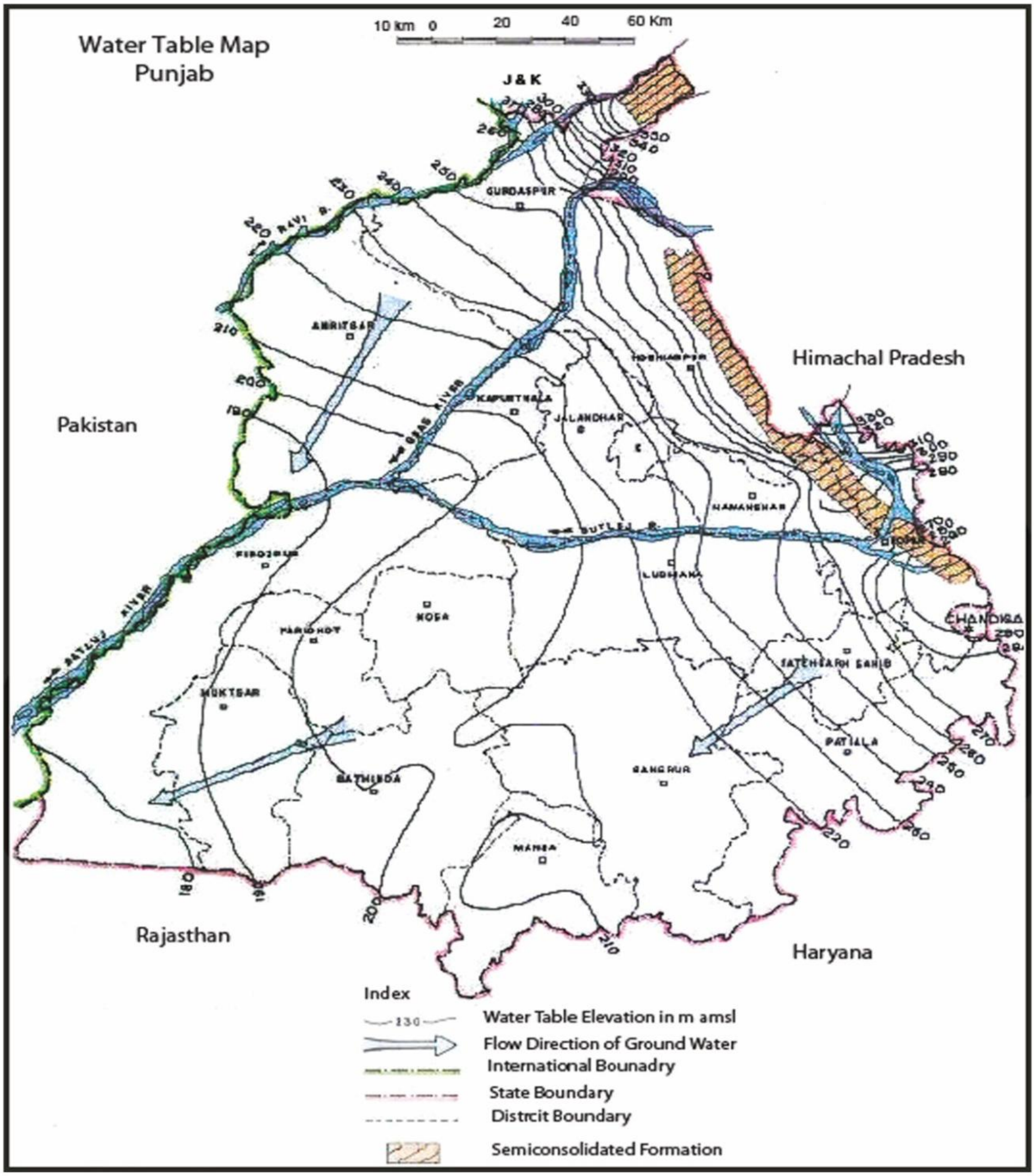
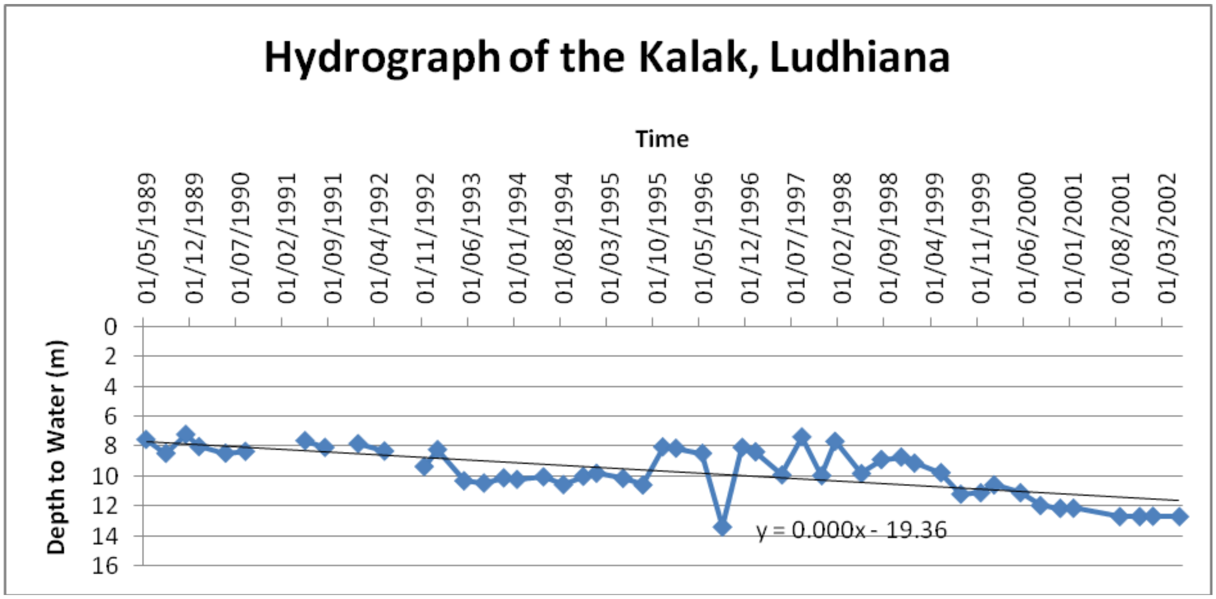
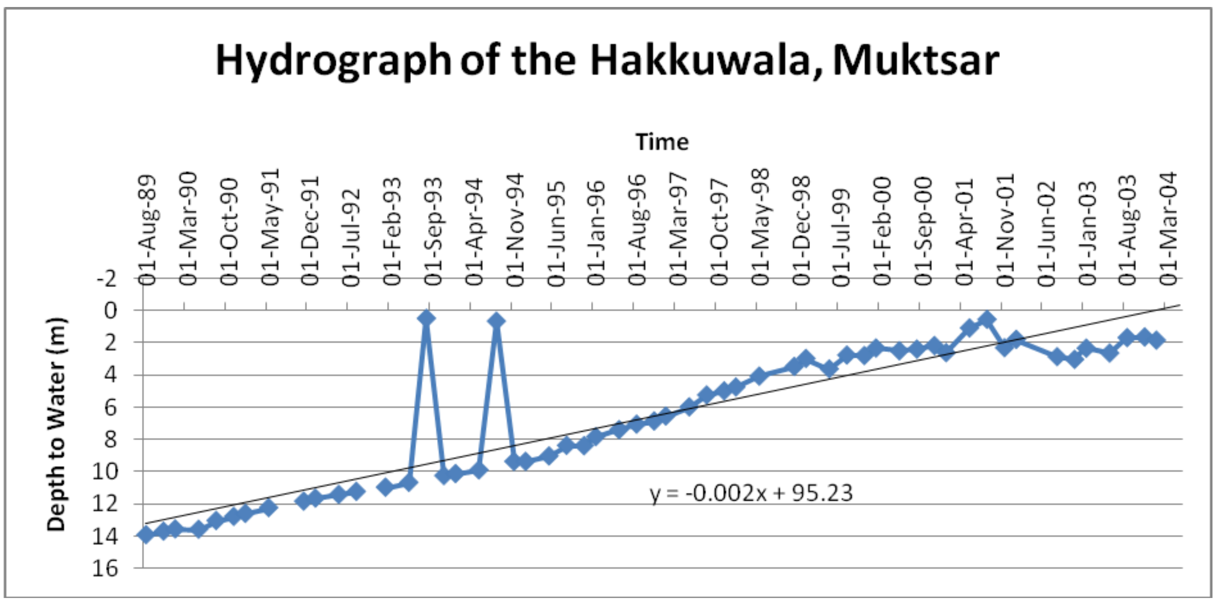
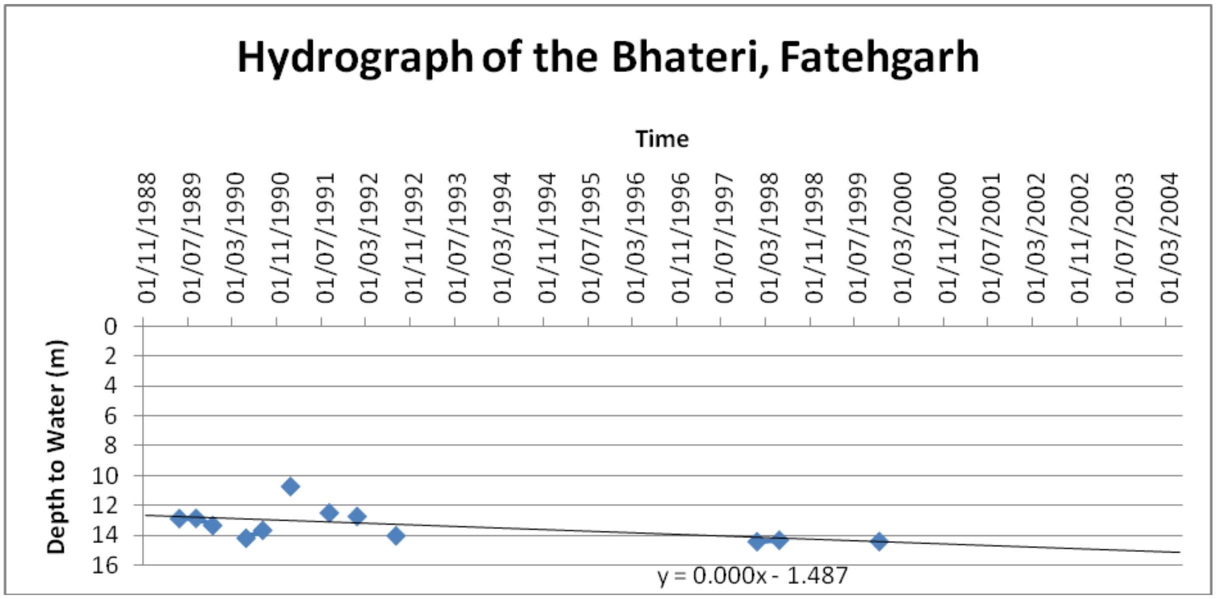
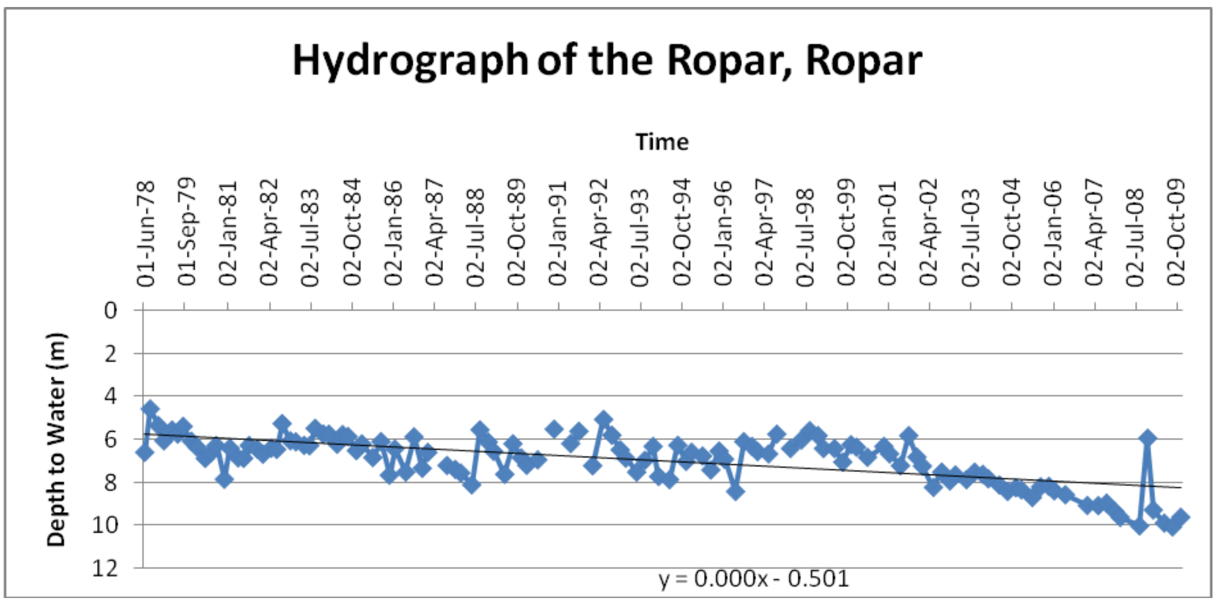


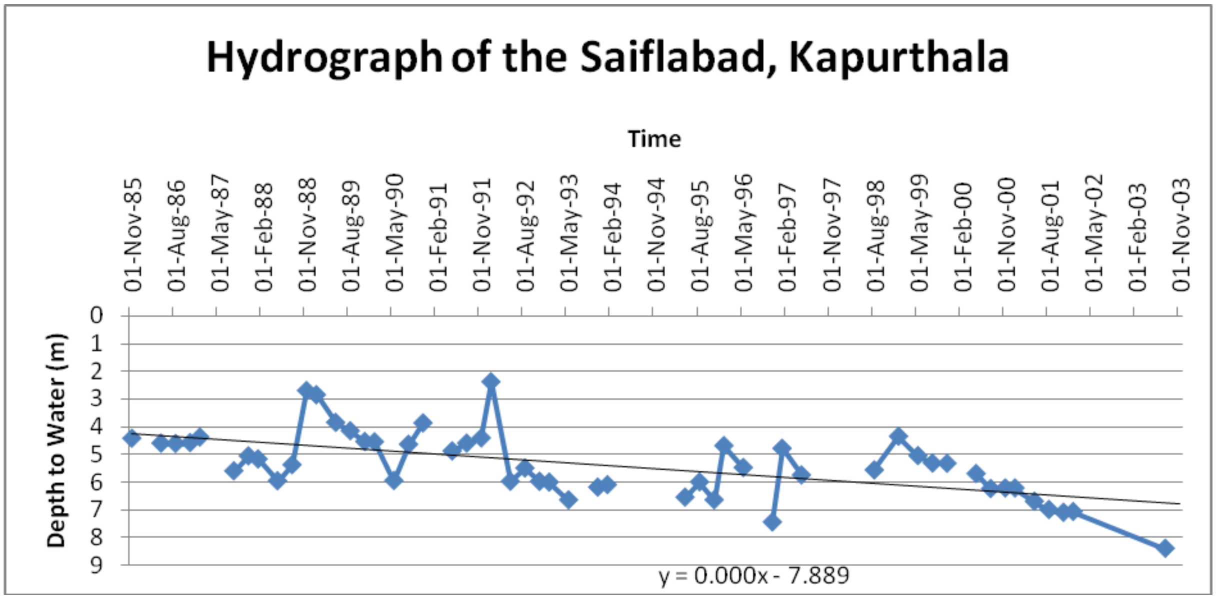
Figure 39 Hydrographs






Hydrograph of the Bhateri, Fatehgarh
Time
01/11/1988
01/07/1989
01/03/1990
01/11/1990
01/07/1991
01/03/1992
01/11/1992
01/07/1993
01/03/1994
01/11/1994
01/07/1995
01/03/1996
01/11/1996
01/07/1997
01/03/1998
01/11/1998
01/07/1999
01/03/2000
01/11/2000
01/07/2001
01/03/2002
01/11/2002
01/07/2003
01/03/2004
Depth to Water (m)
0
2
4
6
8
10
12
14
16
y = 0.000x - 1.487


Hydrograph of the Ropar, Ropar
Time
01-Jun-78
01-Sep-79
02-Jan-81
02-Apr-82
02-Jul-83
02-Oct-84
02-Jan-86
02-Apr-87
02-Jul-88
02-Oct-89
02-Jan-91
02-Apr-92
02-Jul-93
02-Oct-94
02-Jan-96
02-Apr-97
02-Jul-98
02-Oct-99
02-Jan-01
02-Apr-02
02-Jul-03
02-Oct-04
02-Jan-06
02-Apr-07
02-Jul-08
02-Oct-09
Depth to Water (m)
0
2
4
6
8
10
12
y = 0.000x - 0.501


Hydrograph of the Saiflabad, Kapurthala
Time
01-Nov-85
01-Aug-86
01-May-87
01-Feb-88
01-Nov-88
01-Aug-89
01-May-90
01-Feb-91
01-Nov-91
01-Aug-92
01-May-93
01-Feb-94
01-Nov-94
01-Aug-95
01-May-96
01-Feb-97
01-Nov-97
01-Aug-98
01-May-99
01-Feb-00
01-Nov-00
01-Aug-01
01-May-02
01-Feb-03
01-Nov-03
Depth to Water (m)
0
1
2
3
4
5
6
7
8
9
y = 0.000x - 7.889

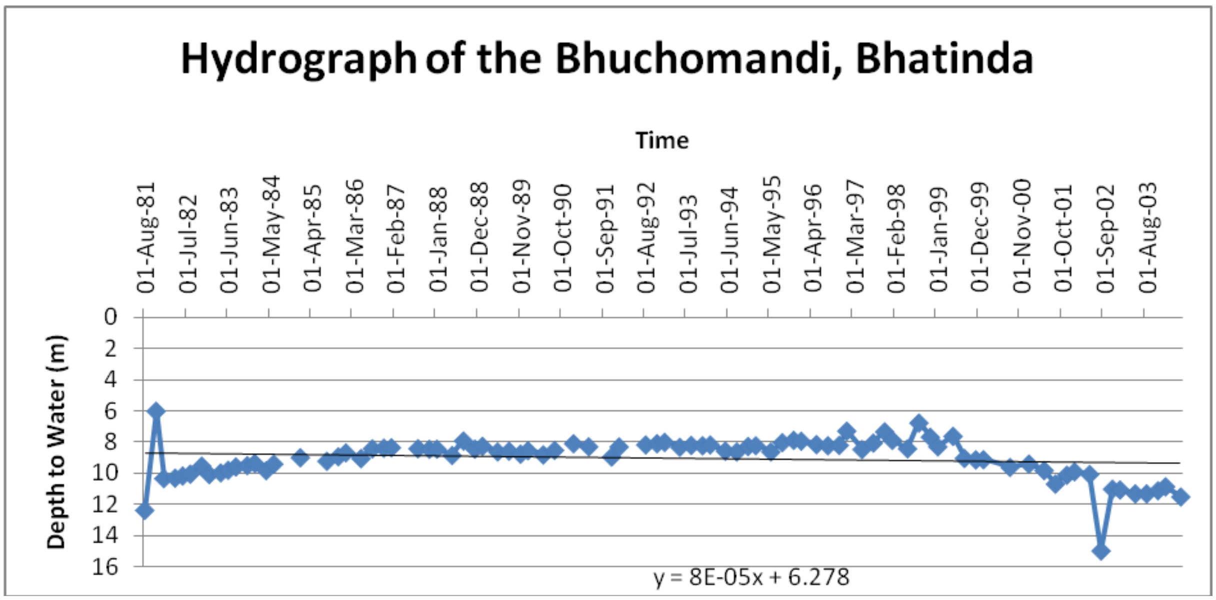

Hydrograph of the Bhuchomandi, Bhatinda
Time
01-Aug-81
01-Jul-82
01-Jun-83
01-May-84
01-Apr-85
01-Mar-86
01-Feb-87
01-Jan-88
01-Dec-88
01-Nov-89
01-Oct-90
01-Sep-91
01-Aug-92
01-Jul-93
01-Jun-94
01-May-95
01-Apr-96
01-Mar-97
01-Feb-98
01-Jan-99
01-Dec-99
01-Nov-00
01-Oct-01
01-Sep-02
01-Aug-03
Depth to Water (m)
0
2
4
6
8
10
12
14
16
y = 8E-05x + 6.278

Figure 40 Electrical Conductivity

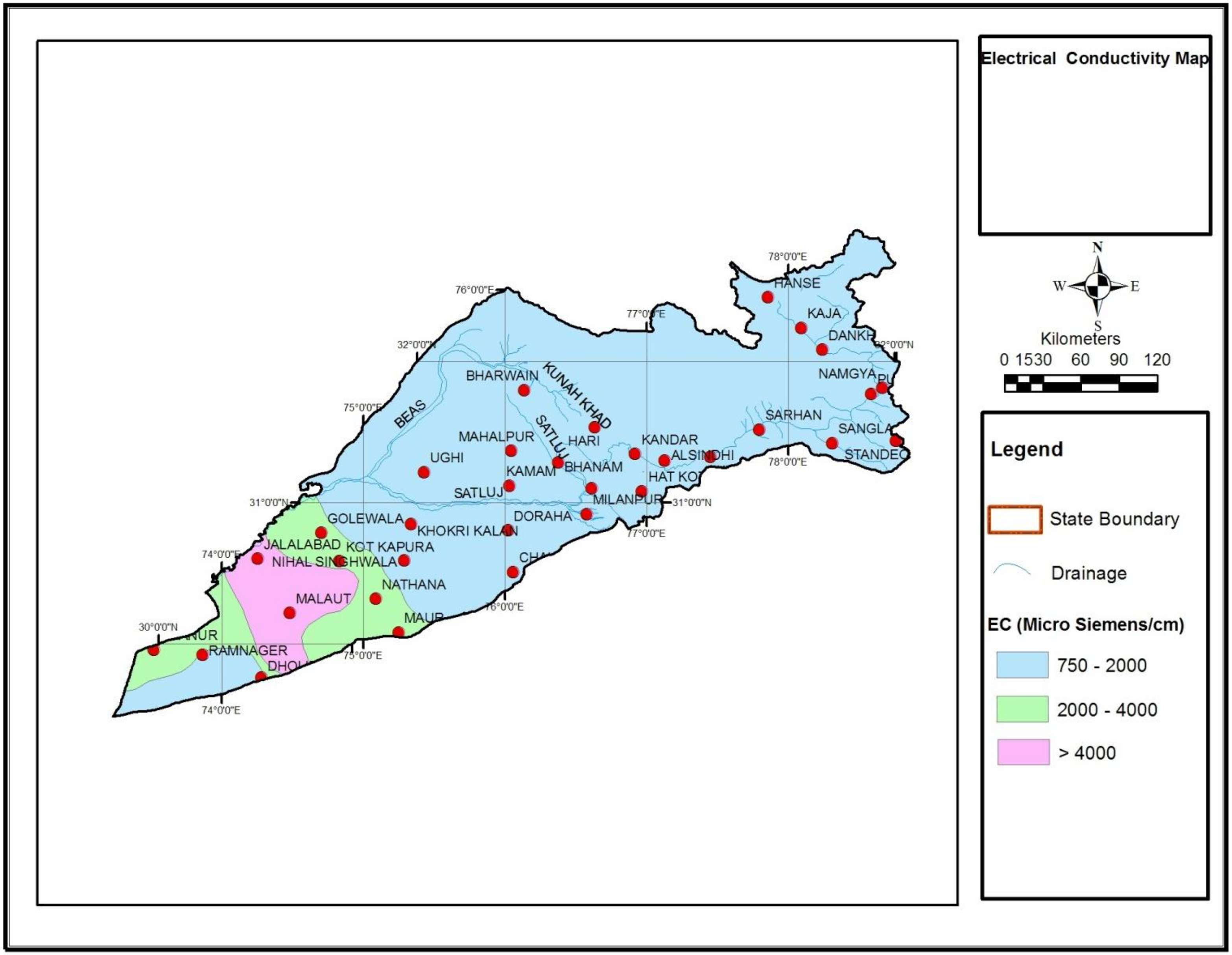


Table 24 District Groundwater Availability

Table : District wise Groundwater Availability & use (in Ham)								
S.No.	District	Annual Recharge	Natural discharge	Net Annual GW Availability	Annual Ground Water Draft		Extent of GW Development (%)	No. of OE-Blocks
					Irrigation	Domestic / Industry		
1	Amratsar	273467	27347	246120	366699	6275	152	16
2	Bhatinda	93047	7698	85349	78412	680	93	4
3	Faridkot	56787	5679	51109	54056	220	106	2
4	Fategarh Sahib	58407	5841	52566	83552	1021	161	5
5	Ferozpur	243758	24376	219383	228769	2367	165	7
6	Gurudaspur	205840	20584	185256	193600	4097	107	6
7	Hoshiyarpur	99992	8175	91817	74603	3536	85	2
8	Jalandher	125781	12578	113203	257084	30033	254	10
9	Kapurthala	69062	6906	62156	124929	1972	204	5
10	Ludhiana	260130	26013	234117	323274	14816	144	10
11	Mana	89375	8936	80421	140412	30	175	5
12	Mogha	135599	13560	122039	214540	2128	178	5
13	Muktsar	92658	8330	84328	51990	160	62	-
14	NawanShahar	73866	7387	66480	114933	1208	175	3
15	Patiyala	181208	18121	163087	264951	3602	165	8
16	Ropar	65161	6516	58645	47717	6743	93	2
17	Sanguor	253573	25357	228216	414055	3688	183	12
	Total	2377694	233402	2144292	3033577	82575	145	
		23.78bcm	2.33 bcm	21.44 bcm	30.34 bcm	0.83 bcm		

Figure 41 Areas Identified for Artificial Recharge

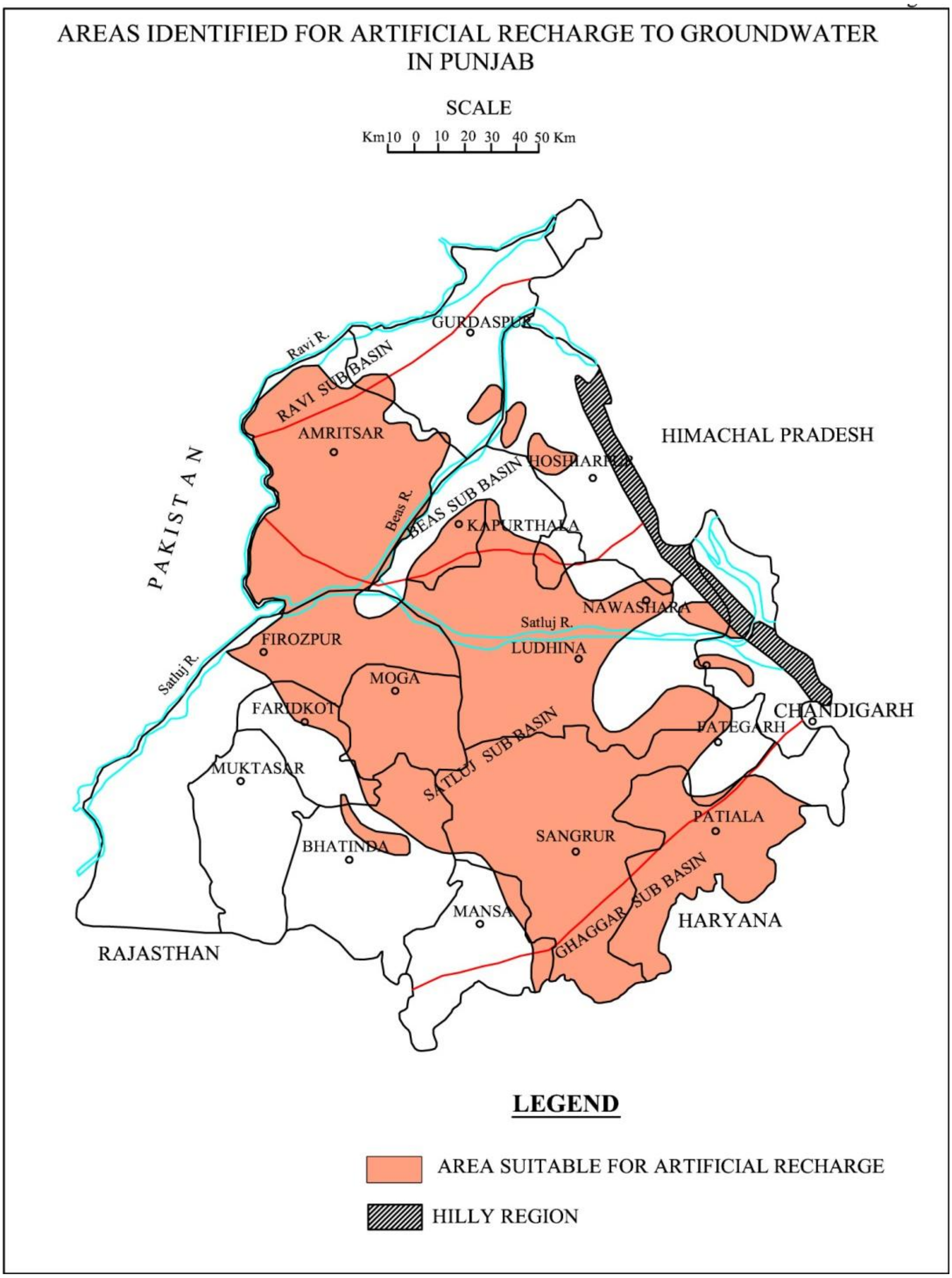


Figure 42 Water Logged and Salt Affected Areas

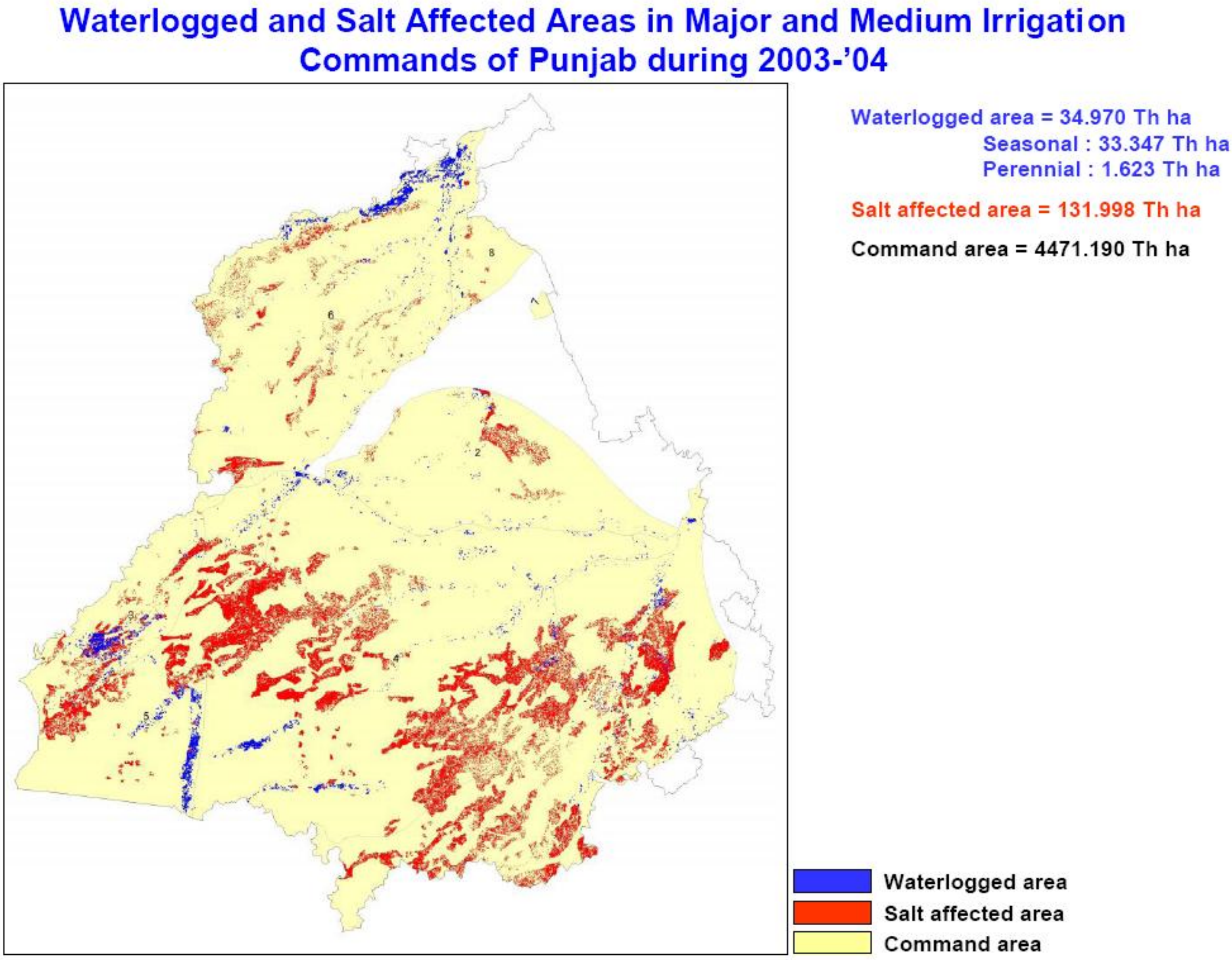


Table 25 On Going and Planned Soil and Water Conservation

ACTION POINTS		SCHEMES	DEPARTMENT	ROJECT COST(IN CRORES)
1	i	Technology Development, Awareness, Training	Agriculture Department, Punjab & Department of Soil & Water Conservation	11.00
	ii	Resource Conservation through Laser Levelling	Agriculture Department, Punjab & Department of Soil & Water Conservation Punjab	3.00
	iii	Promotion of Timely Transplantation of Paddy.	Agriculture Department, Punjab	150.00
	iv	Under Ground Pipe Line system in place of kacha field channels for Kotla Branch Canal System and Ghaggar Branch Canal System.	Punjab Water Resources Management & Development Corporation Limited Chandigarh	1052.48
	v	Micro lifts on Farm Tanks with Solar pumps	Department of Soil & Water Conservation Punjab	1.00
	vi	Rainwater Harvesting Structures Rain Water Harvesting Structures in kandi Sub – Mountainous Area Rehabilitation/ upgradation of Old Water Harvesting Structures Development of Micro Water Resources in Kandi Area (d) Community Farm Water Storage Tanks (e) Individual Farm Water Storage Tanks	Department of Soil & Water Conservation Punjab	5.00 2.00 5.00 4.50 4.00
	vii	Pilot Projects of Artificial Roof-top Recharge structures	Department of Soil & Water Conservation Punjab	5.00
2		Drafting of comprehensive action plan for augmenting recharge of ground water utilizing surplus rain water runoff and flood waters.	Department of Irrigation , Punjab.	1452.00
3		Promoting less water in crops wherever necessary	-	-
4		Adoption of micro-irrigation techniques such as drip irrigation and sprinkler irrigation for enhancing water use efficiency	Department of Soil & Water Conservation Punjab	6.00
5	a	Promoting conjunctive use of surface and ground water	Department of Soil & Water Conservation Punjab	9.00
	b	R&D to explore new resources for promotion of conjunctive use of surface & ground waters	Department of Irrigation, Punjab.	25.00
6		Consolidation and expansion of programme for renovation , repair and rejuvenation of water bodies	Department of Rural Development and Panchayats Punjab	705.47
Total Project Cost				3440.45

IV. AGRICULTURE

1. Introduction

108. Punjab, is a good example of green revolution in India, is however now at the crossroads. During the mid-sixties, the state's agriculture and economy and contributed significantly in making the country self-reliant in food. Food grain production in the state increased from 3.16 million tons in 1960-61 to 25.66 million tons in 2004-2005[27]. The present agricultural system in Punjab has however become unsustainable and gradually non profitable The state's agriculture has reached at the highest production levels possible under the available technologies and natural resource base and its growth has stagnated. The gains resulting from the success of ever increasing food production over the span of last four decades, have not been without environmental and social costs. Over intensification of agriculture over the years has led to water depletion, reduced soil fertility and micronutrient deficiency, non-judicious use of farm chemicals and problems of pesticide residue, reduced genetic diversity, soil erosion, atmospheric and water pollution and overall degradation of the rather fragile agro ecosystem of the state. The high cost of production and diminishing economic returns in farming are adversely affecting the socio-economic conditions of farmers in Punjab.

109. Minimum Support Prices (MSP) and procurement facilities for certain selected crops have been a key instrument to support the agriculture in Punjab. The Government of India introduced minimum support price (MSP) system under the Agriculture Price Policy since 1965. The minimum support prices are announced by the Government with a view to encourage food grains production, ensuring remunerative prices to the farmers for their produce on the basis of the Commission for Agricultural Costs and Prices (CACP) recommendations. The MSP is essentially a floor price set by government in an effort to stabilize the income of farmers and include full cost of production plus incentives for production. The cost of production is estimated through collection of farm level data in various states by cost accounting method. The sample size for Punjab is 300 farmers in 30 cluster villages (Source: Kalkat *et al*., 2006). These prices are announced by the Government at the commencement of the season to enable farmers to pursue their efforts with the assurance that the prices would not be allowed to fall below the fixed level. It is now widely recognized that the minimum support price policy has been one of the key instruments, along with application of modern technology, to make the country self sufficient in production of food grains. However, currently in the wake of economic liberalisation, there are some confusing perceptions about the relevance of minimum support price policy. The Government of India every year announces the minimum support prices for 24 different commodities, though effective public procurement is operative only in case of wheat and paddy

110. In Punjab, the Minimum Support Price of wheat and paddy crops has encouraged farmers to make investment on large scale on land and water development and increase the area under HYVs of these two crops. In case of other crops, there been quite limited take up despite the market prices in many cases have been lower than the MSP. Since 2000-01, the MSP for even wheat and paddy has been announced with meagre increments. However, the area under these two crops continues to be at peak with little fluctuation not withstanding because of lack of effective market support and low profitability of alternative crops. Hence, despite decline in the margin of profit in wheat and paddy over the last 5 years, these crops are still more popular among farmers of Punjab due to their ease of marketing. The cultivation of wheat and paddy crop rotation is causing irreparable damage to state's ecology especially depletion of ground water table, deterioration of soil health and environmental pollution, but it is very difficult to break this rotation under the present circumstances

111. Punjab has the highest annual per capita consumption of electricity in agriculture sector (247.76 Kwh) among all states and UTs in India (average 81.20 Kwh)[28] The demand for energy in agriculture in Punjab has increased from a r 463 million Kwh units to 7314 million Kwh units from 1971 in 2006 mainly due to ever increasing area under paddy crop. Although it is unlikely that area under paddy would increase further, pumping heads are increasing due to decline in groundwater levels. In view of the ever increasing demand for power by agricultural and industrial sectors of state, the state government is working hard to bridge the gap between demand and supply by resorting to purchase of power from external resources. Punjab's self-generated thermal and hydel power accounts for 75

[27] Source: Statistical Abstract of Punjab, 2005

[28] Statistical Abstract of Punjab, 2005

percent of total power availability and the remaining 25 percent being purchased from outside. For the last four years due to poor monsoon, the state is Further; the power supply to agriculture sector in the state is highly subsidized. It was totally free during the years 1997-2002. The state Government is again providing free electricity to all farmers 2005, thereby benefiting them to the tune of Rs. 4320 million. As per PSEB, Punjab has purchased power worth Rs. 51600 million during 2002-2005 from other sources. This is being purchased at nearly Rs. 6 per unit but is provided free to farmers causing economic loss to the state.

112. Moreover, free power to agriculture sector is also contributing to decline of water table. The policy of free electricity to farmers has resulted in excessive mining of groundwater resources. Farmers use water irrationally, over-irrigate their crop and do not care for power economy (as they do not have to pay for it) by using cheap non energy efficient, poor quality, non ISI mark motors. Erratic electricity supplies result in farmers irrigating when power is available and less on the crop demand.

113. Land tenure is an issue in Punjab; it is reported that 7% of the rural population own 30% of the land.

114. Farmers are reluctant to change from the safe known systems and guaranteed prices of wheat and rice. There are opportunities for the production of pulses such as pigeon pea which can produce 5T/ha over 180 days. There are issues of the long growth period of such crop which affects the viabilities of double cropping. The department of Agriculture is trying to source alternative crops to Padi however at present no financially viable options appear promising.

115. Timely availability of irrigation is an issue-the rigid Warabandi system with very low water availabilities and rotation systems and erratic availability of power are affecting the efficiencies of water applications.

2. Cropping

116. Cropping intensity has been increased from 126% in 1960-61 to 161% in 1980-81 and to further 189% in the year 2005 (Fig. 2.10). As per Ministry of Agriculture, Government of India, statistics for the year 2003, Punjab has the highest cropping intensity in the country followed by 176% of West Bengal, 174% of Haryana, 152% of Uttar Pradesh and 142% of Assam as compared to all India percentage of 132.

117. Paddy is a major crop which has made an impact on the agriculture of the state. The area under paddy has increased from 227,000 hectare in 1960-61 to 2. 6 million ha in the year 2006. In terms of gross cropped area of the state (total area sown once and/or more than once in a particular year), paddy occupied around 4.8 percent of the gross cropped area in 1960-61, increased to more than 25 percent in 1990-91, and then increased further to 33 per cent in 2004-05. The increase in area under paddy has led to decline in area under other major kharif crops like maize, bajra, jowar, sugarcane, groundnut, pulses, etc. The area under maize and sugarcane has declined from 9.77% and 2.25% of total gross copped area of state in the year 1970-71 to 1.94% and 1.08% in year 2004- 05, respectively.

118. Wheat has, however, been the dominant crop of the state in Rabi season from the very beginning. In 1960-61, 29.58 percent (1.400 million ha) of the gross cropped area was under wheat, which increased by about 44 percent in 1990-91 and has thereafter remained almost the same (3.5 million ha in 2006). The increase in wheat cultivation has been at the expense of cutting down the area under other Rabi season crops especially gram, barley, rapeseed, mustard and sunflower.

119. Punjab also has a potentially productive belt of cotton covering a sizable part of its cultivated area. This belt suffered since mid-nineties due to decline in productivity and pest attacks. The area under desi cotton has decreased from four percent of total gross cropped area in 1960 to less than one percent in year 2005. The area under American cotton has been fluctuating around 5 percent of total gross cropped area of Punjab, which is further expected to increase due to introduction of Bt cotton varieties.

120. Area under total pulses and oilseeds has reduced sharply. This includes many leguminous crops like groundnut, lentils and guar (nodules on the roots of leguminous plants convert atmospheric

nitrogen compounds through nitrogen fixation that can be used by plants). The area under total pulses recorded a sharp decline from 19 percent in the early sixties to less than 0.5 percent of total gross cropped area of the state. The total area under oilseeds also declined by more than 70% in the last 45 years. Over the last forty years the farmers of Punjab abandoned their traditional cropping practices in favour of the government-supported wheat-rice cropping method. However, this is causing degradation of soil including nutrient imbalance, depletion of underground water table (up to 75 cm per year), abuse of pesticides and fertilizers leading to several environmental and health hazards, besides creating economic and social imbalances. It is also creating serious market clearance problems during peak harvesting time. The reduced crop diversity index over the years due to monoculture of wheat and paddy has further resulted in resurgence and development of resistance in pests and has also affected the population of natural enemies of pests. Moreover, in the past years, in order to sustain paddy crop, the industrial, domestic and commercial sectors of state have had to face frequent scheduled and unscheduled power cuts to divert electricity to farm sector during June and August

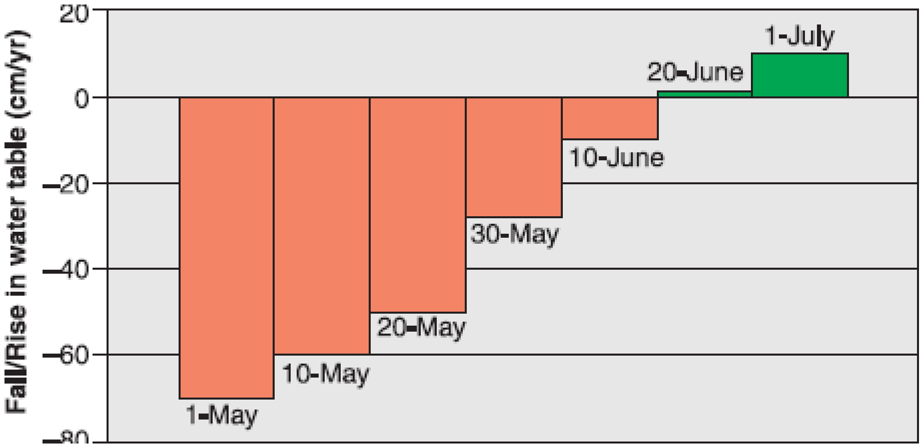
3. Agriculture Diversification

121. Crop diversification refers to a shift from one particular cropping system to a varied and multi cropping system to stabilize farm income (particularly on small farm holdings) and protect our natural resources. There is an urgent need in Punjab to diversify into new areas like vegetables and fruits, oil seeds, pulses and allied fields such as dairy farming, poultry, piggery, etc. As already discussed, the Government of Punjab had launched a multi crop multi year contract farming scheme to give boost to crop diversification in 2002. The programme is being implemented by Punjab Agro Foods Corporation (PAFC). So far more than 0.186 million ha acres is covered under crops other than wheat and paddy like hoyla, winter maize, sunflower, drum wheat, moong etc. involving 0.1 million farmers under this program (Source: Punjab Agro Foods Corporation, 2005).

4. Conservation of Water in Agriculture

122. **Promoting timely transplantation of paddy:** this is seen as one of the most effective strategy to control the falling water table in the state. In the recent past it has been observed that farmers have started early transplantation of paddy due to which the scarce canal water is required to be supplemented by withdrawals of ground water to meet the additional irrigation demands. Experiments conducted by Punjab Agricultural University indicated that if paddy is planted by 10th May, the ground water level recedes by 60 cms every year and if it is planted by 10th June the depletion is not more than 10 cms (as monsoons usually arrive by this time). Further, the chances of depletion of ground water further recede if the paddy is planted by June 20 as shown in Figure 43. The Evapo-transpiration requirement of paddy declines with the delay in the date of transplanting. Thus PAU has advised the farmers to defer transplanting of paddy till June 15 from kharif 2006. This technology is widely promoted by PAU, Department of Agriculture, Krishi Vigyan Kendras (KVKs) and the Farmers Advisory Service Scheme (FASS) by organizing various extension activities. Farmers have also been educated during Kisan Melas, in addition to special radio and TV Talks. This also saves farmers from inconvenience during procurement as early sowing leads to early arrivals of paddy in the market, whereas government procurement start only in the first week of October. From 2010 survey it would appear this advisory seems to be gradually accepted.

Figure 43 Change in Ground Water Table Depending on Date of Transplanting Paddy[29]



123. **Promotion of Zero Tillage**: The department of Agriculture is promoting “Zero Tillage Techniques” since 2001, in areas of state where wheat is sown after harvesting of rice. Zero till system refers to planting crops with minimum of soil disturbance. The wheat seeds are placed directly into narrow slits of 3-4 cm width and 4-7 cm depth made with drill fitted with chisel, “inverted T” or double disc openers without land preparation. Another novel approach with much promise is the use of “Happy Seeder”, which combines stubble mulching and seed drilling functions into one machine. The emphasis is on conserving moisture and residue management. Apart from benefits like proper mulching of paddy residue instead of burning, timely sowing, reducing run off and soil erosion, lesser deep percolation and improving soil health by incorporating plant nutrients, the zero tillage increases farmer’s profit by Rs. 2200-3000/- per ha by saving 80% of diesel as wheat is sown in one pass only. Moreover in zero till planted wheat, about 1000 m3 per ha of irrigation water is saved due to planting in residual moisture from the previous rice crop and application of a light first irrigation. About 30-50% of water is saved in first irrigation. The area under zero tillage in Punjab has increased from 6800 ha in 2001-02 to 413'000 ha in 2005-06 As per information provided by Punjab Agricultural University, zero tillage sowing of wheat on 412,000ha in state during Rabi season. during 2005-06 has reduced the consumption of diesel by about 20million litres and also reduced the emission of CO2 to the tune of 53.6-64.2 million kg in the environment on the basis of conversion factor of 2.6 kg of CO2 per litre of diesel burnt.

124. **Adoption of ridge planting method of paddy**: A novel resource conservation technology of planting paddy on ridges is becoming popular amongst the farmers in the state especially in villages on the outskirts of Ludhiana. This method of cultivating rice saves 40% water as no puddling is required. The innovation has been developed by JDM Research Foundation and recognized by Agriculture Technocrats Action Committee of Punjab (AGTC). The paddy seedlings are transplanted on to ridges spaced 24 inches apart with furrows that are filled with water. While the crop is irrigated daily for the first week after transplantation, subsequent irrigation is done at weekly intervals with special attention during tillering and grain setting stages. Since less water is used than the flooded rice fields, about 30% less fertilizer is applied in the ridge-furrow system of paddy cultivation. In June 2006, Markfed announced contract farming of 20,000 hectares of basmati in 12 districts of Punjab through ridge planting method. Recently, PAU has also recommended growing paddy on ridges mainly on heavy soils.

125. **Artificial recharge of ground water**: The Central Ground Water Board (CGWB) (North zone) has undertaken various schemes jointly with state departments like Irrigation, Soil Conservation and Agriculture for artificial recharge of aquifers to arrest the falling water table in the state. The board has also been carrying out exploratory drilling for identification of aquifer systems, demarcation of potential aquifer zones and evaluation of aquifer characteristics, etc. The Board has drilled 142 exploratory wells, 154 observation wells, 22 slim holes and 75 piezometers in various parts of Punjab, till March 2004.

[29] State of the Environment Report and Dept of soil science Punjab Agricultural University

126. SRI The use of SRI has been promoted by the Department of Agriculture. The level of interest and uptake has been very low. Farmers are reluctant to adopt the system due to the additional labour requirements; rice production in Punjab is popular partly due to the easy application of mechanisation. Farmers are not convinced of the water savings and under the present policies of no charging for surface or groundwater there is no incentive for farmers to take on SRI.

127. **Promotion of micro irrigation techniques**: Modern irrigation methods like drip and sprinkler have been recognized as the most efficient methods of irrigation, which save water and at the same time enhance the quality and quantity of farm produce, particularly fruits and vegetables. A centrally sponsored scheme on micro irrigation was started in the state in the year 1992-93 with a focus on horticulture crops under the National Horticulture Mission. The scheme is being promoted and implemented by Department of Soil and Water Conservation, Government of Punjab. Under the scheme assistance in the form of subsidy of 50% of cost of drip and sprinkler system is provided to the farmers. (40% assistance is being borne by Central Government and 10% by State Government). The scheme is applicable to small farmers having land less than 5 hectares and growing mainly horticultural crops including vegetables, medicinal and aromatic plants. A total area of 4500 ha (3800 ha under drip and 700 ha under sprinkler) has already been covered under the micro irrigation techniques in Punjab (up to March, 2006). As per the department, micro irrigation increases the productivity by 30-100% with 50% to 70% saving of water in various crops.

128. **Village Ponds and Reedbeds**: the duckweed based rural waste water treatment system in conjunction with fishculture and constructed wetland technology are being promoted and implemented by PSCST in the state for the restoration of clean village ponds. Duckweed is a small free floating aquatic plant often seen growing in thick mats on waters of natural ponds. Besides offering effective waste water treatment, the duckweed technology has the potential of providing economic returns by providing employment opportunities in rural areas. The technology has been promoted by PSCST in 19 villages of Punjab. A constructed wetland project has also been taken up by PSCST in collaboration with M/s CH2M Hill, Canada to promote an alternative low cost technology for sustainable water treatment using reed beds as plant biofilters. Typha and Phragmites are commonly used species. The project has been demonstrated in villages Peepal Majra (District Ropar) and Shekhupur (District Patiala), which were facing the problems of degrading water quality due to influx of sullage and storm water in village ponds.

5. Soil and Water Conservation

129. **Watershed management**: An integrated watershed project was initiated by Central Soil and Water Conservation Research and Training Institute, Chandigarh at District Nawanshahar. The watershed area spread over 627 ha drains into river Sutlej through six seasonal streams/choes (seasonal streams). The entire region was facing degradation due to over exploitation of hill vegetation by humans and animals, leading to denudation of forests and expanding net work of choes which were continually getting deeper and wider with large scale movement of silt along with runoff causing water erosion. The project helped the collection and sustainable use of rainwater by construction of a check dam. A 13.5 m high homogenous earthfill dam was constructed in 1992 to store 13.7 ha m runoff of water from this area. An underground pipeline 2.9 km long was laid for providing water with gravity flow for irrigation and other purposes. Since the implementation of the project there has been a constant rise in cultivated area during the kharif and rabi crops. Area under rabi crops (mainly wheat) has increased from 1.54 ha to 22.07 ha during 1992 to 1999 and area under kharif crops (mainly sorghum, bajra and maize) from 3.55 ha to 24.70 ha during the same interval. Availability of more fodder from the cropped and the catchment areas, has led to increase in number of bullocks and milch cattle also (Samra et al., 2002). Another watershed project has been implemented in foothills of Shivaliks at village Sahoran in Dasuya block of Hoshiarpur District by Department of Soil and Water Conservation under National Watershed Development Project for Rainfed Areas for Integrated Development. The total geographical area of the watershed is 3743 ha and it overs the area falling in villages of Sahoran Kandi, Siprian and Jagiyal. Loose boulder structures, with or without vegetative support, check dams and spurs were constructed in drainage lines for reducing soil erosion and controlling runoff. Ninety five dugout ponds with a capacity of 36 ha m were also constructed for harvesting rain water. Agro forestry has also been given priority under the project by planting 18600 plants of Amla, Date, Subabool, Kikar, Sarin etc. The yields of major crops i.e. wheat, maize and fodder increased by 30% as compared to the pre-project yield. Milk and horticulture production has

also increased by 25% and 30% respectively. The ground water table of watershed has come up by approximately 2.5 m after implementation of project, thereby increasing value and fertility of land.

130. The Department of Soil and Water conversation has indentified 106 sub-watershed projects in the Kandi area, which forms about 10% of the total geographical area of the state. The main objective of these watersheds is conservation, development and sustainable management of natural resources and enhancement of agricultural productivity in the watershed area.

131. Wetland management: Wetlands are natural source of ground water recharge. PSCST is conducting a wetland conservation and management program in the state. This includes survey of wetlands area and management of water hyacinth, regular flow of water, afforestation, fencing and construction of ponds and mounds. These activities are sponsored by Ministry of Environment and Forests, Govt. of India. Wetland evaluation programs are also being conducted with wetland International - South Asia. Awareness projects are also being carried out under UNDP.

132. The Department of Soil Conservation, Punjab is taking various land reclamation and soil conservation measures throughout the state to prevent soil erosion due to flash floods in hilly areas. More than thousand hectares of land has been reclaimed from gullies up to the year 2006. Maximum reclamation has taken place in the districts of Hoshiarpur followed by Ropar and Gurdaspur, where land in each district has been brought under cultivation during the past five years. The department had reclaimed more than 0.1 million hectares area in the state by land leveling and waste land development works. The maximum land levelling, wasteland development work and ravine reclamation have been carried out in Ferozpur, Faridkot and Amritsar districts. Sand dunes are also being reclaimed gradually to reach the good soil in the southern areas of the state for brining it under cultivation..

133. Laser levelling is the latest land management technique through which vast tracts of land can be levelled with high precision. Precision levelling of agricultural fields helps in conservation of irrigation water by increasing water application efficiencies, top soil management, land saving, uniformity of crop maturity, reduced weeds and increased yield. The department initiated the programme through the purchase of levellers which were being used for demonstrative purposes. The use of levellers has now become very popular and there are reported to be around 1000 levellers in operation mainly in the private sector.

V. IRRIGATION AND DRAINAGE

A. Irrigation in Punjab

134. The Government has planned and built a number of multipurpose storage projects over the rivers Sutlej, Beas and Ravi. To utilize the stored water for irrigation, expansion of canal infrastructure and remodelling of the existing canals was carried out in the post independence period. A map of the irrigation network is given in Figure 44.

135. The state of Punjab has a well developed canal systems. The major systems are: Upper Bari Doab, Sirhind, Bikaner, Rajasthan, Bist Doab, and Bhakra. Only the Upper Bari Doab canal is taking off from the river Ravi with the other five canal system from the river Sutlej. The Sirhind Canal System is largest system, offtaking from the at the Ropar Head work which was constructed in the year1874-82 and was remodelled in 1952-54.

136. State Water Resource Department have indicated that as against the current water requirement of 4.38Mham the overage available supply is about 3.13Mham. The surface water canals provided about 1.45Mham and1.68Mham is met through ground water, and rainfall. Deficiency is met through over exploitation of ground water. Shortfall in monsoon rainfall causes further over-exploitation of ground water. Cultivation of high water demand crops is reported as the main reason for sharp decline in the water table in the command areas and elsewhere. The state surface water resources systems are fully utilized through the well organized canal irrigation in sustaining the intensive (paddy and wheat) agriculture production. It is reported however that there has been gradual reduction in the canal irrigation and the area irrigated by tubewells has been increasing. As per 2005 estimate, there are 1.2 million tubewells in the state and the ground water is being over seriously exploited to meet the increasing demand of water for irrigation. However in the southern-western parts of the state (with in the Sirhind canal system) ground water extraction for irrigation propose is very low due to the it's brackish and saline quality and the water logging in long track of command area has occurred. Presently the ground water extraction is 145% in the state and out of 137 blocks of the state, 103 blocks are over-exploited 9 blocks are in the critical and semi-critical stage and only 24 blocks are in the safe category.

B. The Sirhind Canal System

1. Water Allocations

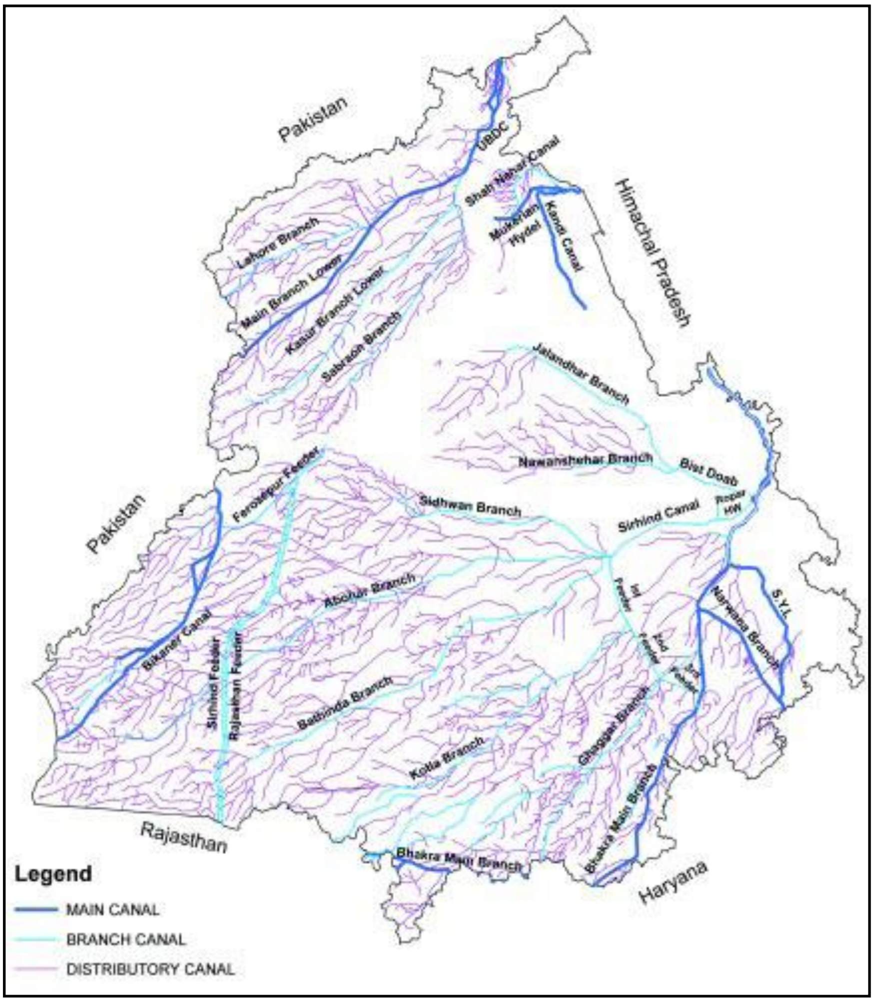
137. The Sirhind canal system is supplied from Ropar headworks constructed in the years 1874-82 to divert waters for irrigation supply through the Sirhind canal system. The headworks were remodelled in 1952-54 when irrigation was extended to include the Bist Doab area on the right bank. The main features of the surface water irrigation system are shown in Figure 5.1. The Sirhind main canal takes off from Ropar and is sub- divided into three main branches: Bhatinda Branch (length 159 km, discharge 2890 cusecs), Abohar Branch (length 109 kms, discharge 3029 cusecs) and Sidhwan Branch (length of 88 kms, discharge of 1750 cusecs), serving districts of Ludhiana, Moga, Mukatsar, Faridkot, Barnala and Bhatinda.

138. Main branch canals are further sub divided into distributaries and minors as a network of distribution system. Farm fields get water by warabandi (rotational water supply) from the minors. Most of the farmers have also installed pumps for the extraction of ground water. Rice wheat cropping system is sustained through conjunctive use of surface water and ground water. Bhatinda Branch distributes it water through 21 distributions namely Denlon, Mholi, Raikot, Kalyan etc as shown it the map. Similarly Abohar Branch has about 19 distributaries and Sidhwan branch has 15 distributaries.

139. The Sirhind main canal has a capacity of 12624 cusecs (357 m^3/s), and commands a cultivable area of 1,359,000 ha (equivalent to 0.26l/s/ha). CWC have provided discharge data for the Ropar Headworks, and for the Sirhind main canal for the period 1990 - 2010. The mean annual discharge of the Sirhind canal during this period was 196 m^3/s, which equates to an annual gross irrigation supply of 450 mm over the cultivable command area. Assuming an overall irrigation efficiency of 50%, net annual surface water irrigation supplies are unlikely to exceed 225 mm. The annual distribution of

mean ten day discharges in the Sirhind main canal is shown in Figure 45. Flows are regulated by the Bhakra Reservoir, and dry season flows are thus maintained as releases are made for hydropower production. Irrigation diversions increase significantly in May and are maintained at a high level through to the beginning of September, and harvest of the kharif crop.

Figure 44 Punjab Canal Network



140. Field outlets from the irrigation system typically have a capacity of 3.5 cusecs per 1,000 acres, which is equivalent to 0.245 l/s/ha or 2.1 mm/day. Rotation is practiced at field outlets on the basis of 10 minutes full supply per acre. This results in 14.7 mm delivery on a 7 day rotation (a gross application of 2.1 mm/day). The system was thus clearly designed for supplemental irrigation during the Kharif season and for irrigation of a reduced area during the Rabi season. During the kharif in the period June to September, average annual gross irrigation at filed level from surface water is of the order of 190 mm, while in the Rabi season between October and February it is of the order of 150 mm.

141. Inter-annual variation in surface water irrigation supplies are shown in Figure 46. The 20 years of record available to the study are not sufficient to permit any conclusions to be drawn with respect to trends in water supply, although the supplies in the last decade have been lower than in the preceding one. The annual irrigation supply at 20% non-exceedance probability is about 185 m^3/s, which is only about 5% below the mean.

142. The distribution of cropping in the Sirhind command in the Kharif season is shown in Figure 47. During the Kharif season paddy rice predominates with about 90% of the cropped area. During the Rabi season wheat occupies about 94% of the area. Cropped areas are very similar in the Kharif and Rabi seasons.

Figure 45 Mean 10 Day Flows Sirhind Main Canal

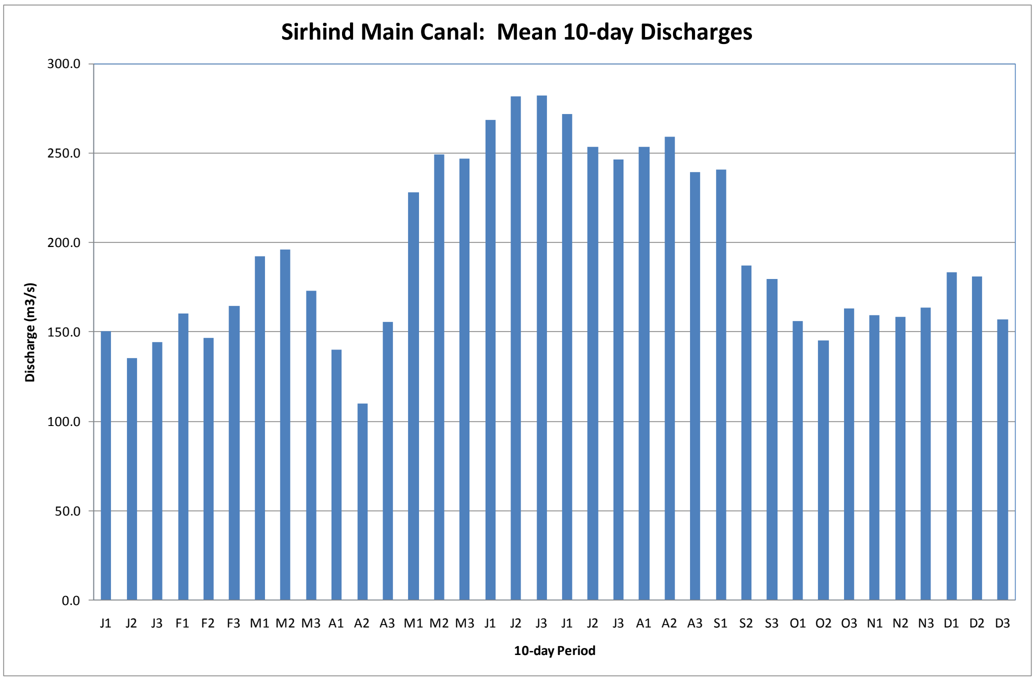


Figure 46 Variation in Annual Irrigation Supplies to the Sirhind Command

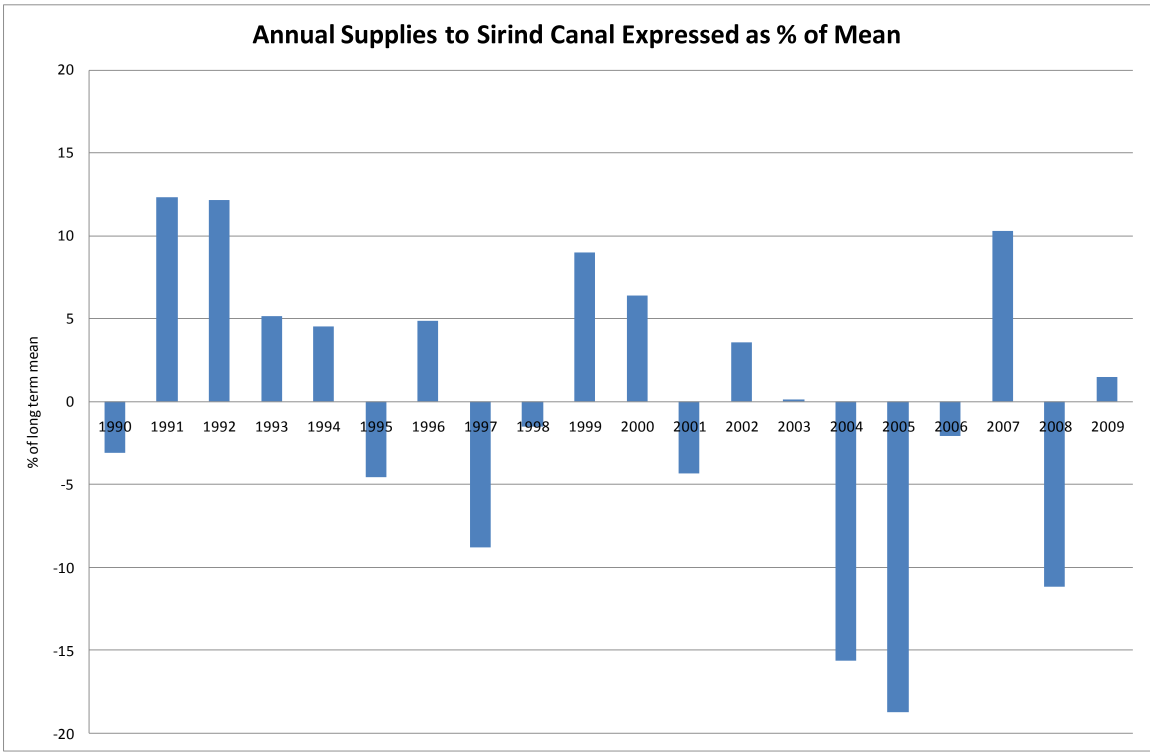
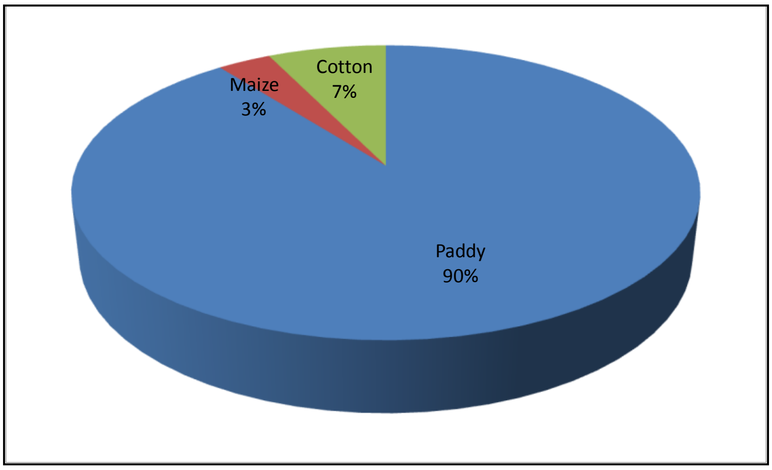


Figure 47 Cropping in Sirhind Command Kharif Season



143. Net irrigation demands have been calculated using data from the FAO CLIMWAT database and the CROPWAT 8.0 package. Data were extracted from CLIMWAT for Ludhiana in the north of the Sirhind command, and for Ganganagar, which is Rajasthan, but close to the southern border of Punjab and the southern extremity of the Sirhind system. At Ludhiana, the calculated average net irrigation requirement for paddy rice was 240 mm, and at Ganganagar was 690 mm. The net surface water supply in the Kharif season is likely to be of the order of 90 mm or less, leaving a significant part of the water requirement to be met from other sources. The net irrigation requirement for wheat during the Rabi season was calculated to be 100 mm for Ludhiana, and 195 mm for Ganganagar. Net water supply during the dry season is likely to be 75 mm or less.

144. Irrigation requirements clearly increase significantly towards the southwest of the Sirhind command, and surface water is only capable of meeting less than half of the overall demand. The Water resources Department of Punjab indicated that surface water was only providing 25% of the total irrigation supply.

145. There is clearly a significant variation in irrigation demands across the Sirhind system, with the highest demands at the tail ends where delivery is likely to be poorest. In the north of the Sirhind command, annual precipitation is of the order of 730 mm, and annual potential evapotranspiration of the order of 1400 mm. Given a gross irrigation diversion equating to 450 mm, the figures calculated for field delivery tie up reasonably well. Net surface water supplies will be of the order of 200 - 250 mm.

146. The annual crop water requirement at Ludhiana is of the order of 850 mm and the annual input to the water balance of the order of 1200 mm. At Ganganagar, the annual crop water requirement is of the order of 1075 mm, and the annual input to the water balance is of the order of 680 mm (assuming surface irrigation to be equally distributed across the system). The Water Resources Department of Punjab estimate that groundwater abstractions exceed recharge by about 50% and the situation is clearly unsustainable. Measures required to get back to sustainable water use would include:

- a change to more drought tolerant crops i.e. move away from rice - cotton would be better particularly in the southwest where salinity is also an issue; with a change in cropping there could be a change in irrigation technology (basin to furrow) leading to improved efficiency;
- a reduction in the irrigated area
- deficit irrigation in all areas

147. The irrigation duties in the Sirhind system clearly vary quite significantly across the command area, and the spatial variability in the system has to be considered in developing the framework plan. It is not known to what extent duties are at present varied.

2. Problems Faced by Farmers

i) Sharp decline in the ground water table has led to deepening of borewells for ground water pumping. Farmers are suffering due to increasing capital and operating costs of ground water extractions.

ii) Ground water recharge schemes are not popular. Ground water quality is also deteriorating. High cost of ground water and its soci-economic and environmental impacts are real threat to the agriculture.

iii) There is lack of remunerative alternative to high water consuming rice cultivation. SRI cultivation has not become popular. Soil moisture conservation practices are not popular.

iv) It is reported that events of intense rainfall are increasing. Such rainfall water can not be conserved and it disturbs the agriculture activities. Also the extreme weather condition like cold and heat waves, frost etc is adversely affecting crops.

v) Water logging and salinity in lower Sirhind Canal system in Bhatinda district has adversely affected crop cultivation.

vi) Availability of safe drinking water is also becoming a major problem in the command areas. Ground water aquifers are increasingly getting contaminated due to seepage agriculture chemical and fertilizers and also due to disposal of industrial wastes. Many farmers are reported to be using domestic reverse osmosis water filters but poor farmers and agriculture labour consume untreated water. Due to over-exploitation of ground water, the contamination of aquifers is reported as unmanageable situation.

3. Ongoing Water Resources Development Programmes

148. There is no scope to expand the water resources beyond the fully utilized Bhakra multipurpose dam project. Improving the efficiency of water management. is the only option for enhancing and sustaining the agriculture productivity? The State Government is presently undertaking the modernization of the canal systems. Lining of some of the canal system has been taken up in phases under World Bank aided phase-I and phase-II lining project, when the length of 5554 km and 1092 km of channels respectively were lined.

149. The Sirhind main canal runs 60km up to Manpur Head from where Patiala feeder, Sidhwan Branch canal, and combined Branch canal offtake. Sirhind canal systems which is about 125km old systems is providing irrigation to the Districts of Ropar, Ludhiana, Sangrur, Barnala, Bathinda, Faridkot,Muktsar, Moga and Firozpur. Changes in the cropping patterns, poor maintenance of canals and shortfall in the water supply, contribute towards reducing the canal flow gradually along the length of canal, so much so that often tail ends do not get water. Punjab Government has prepared a project to undertake “Modernization and Renovation of Canals being fed from river Sutlej. The project proposed of rehabilitations of Bhatinda branch, Abohar branch and Sidhwan branch of Sirhind canal system and main canal to distribution net work of Bist.

150. The Doab Canal System Project proposes (i) restoration / strengthening of existing banks; (ii)side lining of main canal by keeping bed on unlined to support ground water recharge; (iii) remodelling / and repair of head and distributory regulators, bridges and drains. The cost of the above for Sirhind canal and Bist Doab system is estimated to be Rs.734 crore which has been approval by CWC and Planning Commission. The estimated improvement of the irrigation area is given Table 26 below.

Table 26 Cropped Irrigated Areas

. No.	Name of crop	Area under irrigation	
		Pre rehabitation	Post rehabitation
A	Kharif crops		
i)	Paddy	599,950	786,310
ii)	Maize	21,990	28,730
iii)	Cotton	48,670	58,539
	Total	666,611	873,679
B	Rabi crops		
i)	Wheat	626,611	821,260
ii)	Oil Seeds	40,000	52,419
	Total	666,611	873,679

151. The project authorities have indicated that project will restore irrigation as per original design of the system which will enhance the system area by about 30%, by reduction seepage and percolation by way of side lining and other renovation works. The project has estimated that sidelining of these branch canals are not likely to affect the ground water recharge as the leakage from the side slopes does not

contribute significantly to the aquifers. The project authorities have worked out the saving of canal water of 153 cusecs and 70 cusecs by side lining of 328 km length of proposed Branch canals of Sirhind canal system and 460 km length of Bist Doab System.

152. The CADA Area and Water Management programme is providing a Rs700 crore assistance to line the minor water courses.(field channels) The programme which is funded 60% from central government, 40% state government and 10% farmers ins providing brick lining of the channels. Of the 120,000km of water courses, 45,000km have already been lined, 12,000m are ongoing and 30,000 will be taken up in the near future. The cost of the lining is is Rs700 to Rs 1100/m equivalent to Rs15000/ha of which Rs7500 is paid for by central government. The rate is too low and realistically should be Rs25,000-30,000/ha. Quality is reported as a problem

153. The Punjab government has recently given approval for a Rs.1440 crore project of relining the Rajasthan and Sirhind feeders, to be completed in next four years. The government has also given a commitment to providing regular funds to clearing and cleaning of canals.

C. Drainage

154. The lower part of the Sirhind Command area suffers from problems of drainage and salinity. The problems arise due to the flat terrain and inadequacy of natural drainage, even though the annual low levels of annual rainfall. Irrigation in the last few decades has led to a steady rise of the watertable. To counteract this, an extensive programme was started to minimize groundwater, recharge by improving surface drainage, lining canals and distributaries, and more recently, tertiary canals and watercourses. In contrast the northern parts of Punjab the groundwater is fresh. In these areas, the increased abstraction from wells has kept the water table. under control. On the other hand, in the irrigated areas of south-western parts of Punjab the rainfall is low. The groundwater is brackish to saline in these areas. Waterlogging, salinity and alkalinity problems have arisen in Faridkot, Ferozepur, Muktsar, Bathinda and Sangrur districts. The water table in the affected districts rose at the rate of 15–20 cm per annum due to introduction of canal irrigation network and inadequate drainage systems. According to an estimate, about 85,000 ha of agricultural land in 332 villages of Faridkot and Muktsar districts are severely affected by waterlogging and salinity3. The groundwater in many parts of southwest Punjab contains high concentration of dissolved salts with electrical conductivity (EC) varying from 2 to 7 dS/m and residual sodium carbonate (RSC) being greater than 10 me/l up to 10 m depth2. In general, groundwater salinity of this area increases with depth and the water is not fit for irrigation and drinking purposes. The Punjab government has announced Rs14.41 billion projects for re-lining of the Rajasthan and Sirhind feeder canals. The project, expected to be executed within four years, and should reduce canal seepage and some of the salinity issues.

D. Flood

155. The massive retention of the Bhakra absorbs the flood flows; the reservoir has only filled a few times since construction. In 2010 it filled to its design level, flood was avoided by careful management of releases. A DSS is being set up to assess the obtain early information on the risk of flood and develop appropriate reservoir operation routines. Flash floods occur in the minor tributaries which have no storage. Although localised flooding during periods of heavy rain is an issue major river flooding is not reported. Large releases from Bhakra are reported to be affecting flooding in Pakistan.

E. Potable Water

174. Drinking water is distributed through piped networks managed by government. Sources are both from treated ground and canal water. Most of the major centres including Chandigarh are served by canal water. The quality of the canal water is mainly good with low levels of silt which settles out in the Bhakra reservoir.

175. The primary source is piped supply with 90% of the villages are served with piped supply of water. If any household is not enjoying house connection for piped drinking water, then it uses the community connections (public stand-posts) for obtaining drinking water. Private Borehole based ground water for drinking is used for drinking when the piped water is not available.

156. There are Water Quality problems mainly in the groundwater; high levels of fluorides and in some places arsenic contamination is being reported. Fluoride causes yellow teeth and damages teeth and bones. Arsenic is reported to have cancerous effect. Treatment of Ground water for salinity, fluoride, arsenic and silt in at tail in surface water for drinking purpose has been demanded.

157. There is some divergence in views of stakeholders. Government officials feel drinking water is not a problem and the Government has taken every step to provide safe drinking water. The present system of providing safe drinking water to the population is costly. Some villages have community level RO (expand) system for water treatment. This is provided by the government. But the villages without RO system are aware of the benefits in neighbouring villages and have expressed preference for that through contribution of money but the service reciprocation is longer than promised by service provider.

F. Water Management

1. Surface Water Systems

158. Irrigation water is allocated based on the Warabandi system developed in the middle of the 19th century to manage the irrigation system built at that time. Warabandi means fixing of turns for irrigation water for each farmer on a watercourse. There are two types of warabandi namely "Kacha" and "Pucca". The Kacha warabandi is arranged by the farmers themselves. Rotation is on a 7 day rotation. The canal department regulates the supply of water and fixes the turn of each farmer in a give crop year. This is called Pucca warabandi. If any farmer violates this arrangement, he/she is liable to prosecution under the Canal Act. The farmers who receive water from the watercourse, in the area of what is called the "Chak", are on a seven-day rotation schedule. Each farmer is assigned what is called a proprietary right to a period of time every week for which he is entitled to all of the flow in the watercourse. After every year the turn of each farmer is rotated i.e. if farmer X has a turn in the day time, in the next rotation his turn is shifted to night time. In this way, this system of irrigation turns is operated without any serious problem of equity as far as irrigating one's fields during the night are concerned. The rotation's duration varies from one week to 10 days at a given watercourse in different areas. In ease of canal closure, a farmer missing a turn loses his water.

159. The Warabandi system is supply-oriented and irrigation turns are not based on demand.. The outlets from the distributories are designed to discharge a fixed supply of irrigation water whenever the distributory is running. These outlets (called "Moghas") are fixed open at a given discharge rate and are built of concrete and with a steel insert to avoid tampering by farmers and allow good flow characteristics. There is no gate to close off the canal if there is no demand.

160. A unique feature of the original concept of Warabandi is that the duty is sufficient only to provide adequate irrigation to one-third of each farmer's CCA in a normal weather year. This system of water allocation in the Subcontinent was evolved to promote extensive settlement of the region and to avoid famine. The objective behind such a pattern of distribution for water was to irrigate the maximum area and service as many farmers as possible. Warabandi is designed as a system for equitable allocation not crop needs.

161. The rotations and allocations are managed by the irrigation department it was noted that farmers do not have any formal role in the management of the main supply system. Therefore, there is no opportunity for the constructive involvement of farmers in any of the decision making processes that ultimately affect them. As a result of this lack of formal opportunity, farmers have found other ways to be involved in the operation of the main supply system. though not documented by an it was evident that farmers, particularly influential ones, could manipulate the operation of the system to their benefit.

162. Various studies have been carried out regarding the efficiency and equitability of the Warabandi system. Quite large variations from the design allocation and actual allocations are recorded, especially at the tail end of the system. This inequity is partially caused by the higher than designed water surface level along the upper reaches. Sedimentation, weed growth and other blockages can result in higher water surface levels and, thus, higher withdrawal rates along the upper reaches. Lower than design flows in the lower reaches reduces the water levels and flows into the offtakes.

163. It is argued that Warabandi is not cropping pattern oriented and that it does not cater to the crop water requirements especially for the high-yielding varieties (HYVs) of crops. In the Sirhind the water allocations the shortcomings in the surface water system are made good from groundwater.

164. Allocations to distributor canals are made at the regulator gates according to an indent of requirements from the various water managers. Measurement is made using the gates and measurement of upstream and downstream water levels.

2. Ground Water Systems

165. The use of groundwater in Punjab originated largely around the introduction the HYVs of wheat and rice in late nineteen sixties and mid seventies. The area under HYVs of wheat has increased from 69% 1970-71 to 100% by 2001.

166. Similarly, area under HYVs of rice comprised 33% of total area under rice in 1970-71, to 95% in 2001 and 100% by 2005. The surface water irrigation with extremely low water duties were unable to meet the needs of HYVs and the relatively good availability of groundwater has met this gap and has led to the very fast growth of HYVs and the expansion of tubewells which are now providing 70 to 80% of the water demand. The number of tubewells has increased from 0.5 million in the 1960s to around 2.3million in 2010.

167. There is quite limited information on the operational mechanisms and efficiencies of the tubewell systems. Similar to the surface irrigation it is very much supply driven with water availability defined by the capacity of the pump installed and the availabilities of power. There is a very low fixed charge for power Rs50/hp/month which is not always collected. With no volumetric charging for groundwater pump whenever power is available irrespective of the crop demand. In most areas it was reported that farmers received 4 to 5 hours per day

3. Conjunctive Water Use

168. There was little evidence of management systems for conjunctive water use. Within the farmer water courses, it is understood that some negotiations of the Warabandi allocations takes place. Farmers also sell groundwater to small holders with no tubewell. The Warabandi allocations do not consider the availabilities of groundwater or any methodologies to optimise the supply. The south west part does receive higher irrigation duty but this is to compensate for the lower rainfall. Major investments in lining are being undertaken and there was a decision to limit the lining of some canals to side lining to ensure some continued recharge of the groundwater. There are a number ongoing programs under Central and State Government to increase irrigation efficiencies. Unfortunately these only consider surface water efficiencies.

VI. WATER SECTOR COMMUNITIES AND STAKEHOLDERS

A. Stakeholders:

169. The inclusive growth paradigm has made it almost mandatory to have stakeholders' participation in the design, implementation of public policy and decisions about the delivery of services (Martin, 2005) and also as peer monitoring group. Stakeholders are those who have an interest in a particular decision, either as individuals or representatives of a group. People who influence or can influence a decision as well as those affected by it can be considered as stakeholders. Community of stakeholders can become active with some specific goal. For out purpose we describe stakeholder as a group who shares identity on some specific respect and shares (any one or all) belief, resources, concerns, needs etc. The size of a community however can vary.

170. A commonly shared vision by all stakeholders calls for a successful intervention be it policy, technology or systemic interventions. the specific goals around the community is to"to examine intervention requirements, scope and strategies to improve the efficiency of water systems and how improved efficiency may be applied to climate change adaptation".

171. Water source ownership is represented by multiple categories of stakeholders not fully coordinated and rules on human interventions on the natural water system if not governed by fully defined rules.

- Primary sources of water flow are natural (rainfall/glaciers) defining the overall constraint on primary water supply. In climate change context adaptation challenge is if the community has knowledge and preparedness to take actions now so that the individuals, households and community becomes resilient to uncertain water supply condition in future without affecting wellbeing (in micro sense we consider current and future income stream of farmers and in macro sense productivity in agriculture to make state domestic product resilient).

- Secondary sources are various institutional sources based on surface water flow: Interstate high level body (e.g ., Bhakra dam, BBMB) in control of surface water flow, WRD and irrigation department owned canal system, Agriculture department owned micro irrigation systems and famers withdrawing water from open access ground water aquifers with variety of pumping technology including submersible pumps.

172. In this sense the stakeholders should be considered as water providers and water users as shown in Table 27.

Table 27 Structure of Users and Providers

Stakeholder	
Water Users	**Water Provider**
Water for final use: Household demand for drinking purpose **Water for intermediate use/input in production process:** Household demand for cooking, hygine and sanitation, bathing, gardening etc. Agricultural water demand for irrigation Industrial water demand for process	**Water suppliers/managers** **Formal:** Government managed water supply department for distribution of canal waterf or irrigation and drinking water Water users association **Informal**: Farmers with pump to lift ground water and sells at a cost either monetized (cash) or non monetized (in kind)

B. Understanding stakeholder perception

173. In the Sirhand Canal system the major water user is agriculture sector with changing and ever increasing demand. The residential sector is also important water user but has a more or less fixed demand for drinking, cooking and sanitation. There is increased demand from industry. The study has therefore focused on farmers, rural households of various income strata (defined by landholding size)

and water managers from irrigation, horticulture and public health and hygiene departments. Source of information is primary first hand data collected through rapid rural appraisal through face to face participatory focused group discussions and community consultations, household surveys. The goal is to identify key issues regarding surface water, groundwater, related water sectors and the environment to help in preparation of strategic framework planning. Also, to examine possible areas of intervention as well as scope, and strategies to improve the efficiency of water systems and study how climate change dimensions may effectively be incorporated in IWRM climate change adaptation roadmaps. .

174. The Objective of such a focussed group discussion (FGD) was to understand :

- stakeholder assessment of current issues related to water
- the problems and causes of issues
- perception of change in climate induced parameters and impact on water resource
- to test the response to potential initiatives to address water issues
- identify possible initiatives that could be further investigated

1. PRA and Household Survey Method Adopted

175. PRA is to support the stakeholders through the process of analysis of the problems and help them identify appropriate response to the difficulties and opportunities. We have used preset questionnaire as checklist to get structured response. Qualitative response during focused group discussions has also been recorded, compiled, assessed and presented in the report. We have followed the conceptual framework of LIFE approach[30] and Nine square mandal in preparation of questionnaire in cooperation with other team members involved in TA. In the sub basin three locations have been identified through prior visits, consultative processes with stakeholders. Locations selected are characterized by primarily diversity in ground water related challenges. ADB-PRA team[31] held stakeholder meetings at the villages with stakeholders assembled in focused group discussion (FGD) in each of the three locations. Primary data has been collected not only from FGD but also through household survey (42 households were covered) and one case analysis of a progressive farmers. These three levels of interview methods have been followed to get community, household and individual perceptions.

2. Sutlej River Sub-basin

176. The primary criterion for selecting the locations of field surveys has been the diversity in ground water availability along the Sirhand main canal system. Three points were indentified; one at the head of the canal, one in the middle and one at the tail end. The objective has been to understand if the stakeholders' challenges in diverse locations reasonably spread over the sub basin. Secondary criteria for survey location selection have been crop diversity, followed by ground water quality and quantity. The site selections have been preceded by investigative field visit[32], consultation with broad categories of stakeholders.

177. Community Perceptions[33]; the stakeholders of various interest groups shared more or less a common vision on current water availability, access, distribution and quality in the region. Diverging views are reflected in quantification of the issues presented below through ranges of values.

3. Current issues and Challenges of Irrigation Water Access

- Formally regulated surface water supply system leaves huge unmet demand in agriculture sector thereby shifting the demand pressure on unregulated ground water extraction at

[30] Ghosh and Roy (2006)
[31] PRA Team Leader: Joyashree Roy, Team members: Dr Duke Ghosh (Post Doc fellow) , Local M.Phil and Ph D students from Punjabi University of Patiala, Department of Economics: Rakesh Sharma, Manprit Singh, Vikramjit Singh
[32] November 2010: Chandigarh,Patiala,Cudsonda, Burjmahma, Bathinda, Wajid kekalan
[33] This is a compilation based on all three visits

farmers' private initiative and cost. Administrators of surface water supply system feel the canal system was not designed to meet water demand for paddy –wheat cultivation based agricultural system in the region. Irrigation demand for surface water is ever increasing since 1970s as farmers are shifting their cropping pattern (continuing in water stressed areas as well) to paddy and wheat cultivation to increase certainty in current economic return. Sugarcane is also cultivated but highly volatile in market price. Traditional maize, cotton (kapas), ground nut are declining. Major driver is level of certainty in current economic return from agricultural production to provide stable income flow to farmers.

- Surface water flow through canal system can meet only 10%-30% of irrigation demand in paddy cultivation and 20-30% in wheat.
- Farmers have high dependence (70-90%) on uncontrolled/open access ground water resources. During consultations it could be assessed that perception of common property/open access resource and knowledge on possible management practices either at theoretical level or from practical point of view is almost nil across all stakeholders. But open to new ideas when discussed.
- Every Village has a pond – where the rain water is stored. The ponds are used by the animals. In only a few villages (in 1 out of 30 ratio) ponds are being used for fishery. Fishery is not popular due to high uncertainty (yield loss) and there is no minimum support price/ insurance. Farmers are very much aware that uncertainty in water supply makes the agricultural activity based livelihood risky and the job itself involves huge health risks. The preference of this livelihood option comes mainly from traditional skill, lack of alternative options.
- Next generation is gradually moving away from agriculture with increasing level of education and migration to cities for higher education or other countries in search for better livelihood option.
- Given the high demand with changing cropping pattern uncontrolled groundwater withdrawal is depleting the aquifers faster is understandable to all and is a matter of concern to all but community feel locked into the situation. Administration explains the lock in by technology choice, ease of operation on paddy-wheat crop cycle, growing labour shortage, market based financial incentive for paddy-wheat cultivation and need for national food security. Farmers feel lock in due the priority of livelihood security through current choice of crop mix which has farm-based income guaranteed by MSP, and free access to ground water resource and availability of technologies to withdraw ground water. At the upper levels (< 50ft) there is no availability of good quality ground water. At levels <100 ft the water is not fit for agriculture except in wet season in Ludhiana. General agreement is water below 30 meter is fit for use. In Bathinda issue is not water availability at upper aquifers but it is of quality and increased salinity.
- Impact of depleting and deteriorating ground water is putting over stress on available surface water at the tail end (Bathinda) as canal water supply has to be maintained all 365 days. This is a concern for supply side stakeholders as they fear lack of maintenance will make canal system inefficient in the near future. But farmers' demand is so high current negotiation at 365 days operation time has become an imperative.
- Flood is not an issue in the region as the region is water scarce. However, drainage is not an issue in south west but needs care in head of the stream.
- Water quality is declining with increasing salinity, fluoride, arsenic in ground water and silt in surface water at the tail end where canals are not lined. This is affecting both crop and human health. Farmers' concern and need for quality management emerged as an important issue.
- Surface water managed by Government though has a price tag but currently distributed at almost free of cost so very high in demand
- Ground water extraction is done at very high private cost. Cost components are of pumps, fuel, labour time for operating it. So affordability defines ownership of pump sets and indirectly extraction ownership on ground water resource in an otherwise unregulated ground water regime.
- Select farmer groups in the tail end are not satisfied with on the field level water availability despite their satisfaction with 'barabandi' allocation mechanism. Some feel high demand on surface water sometimes lead to pilferage, political interference.
- Farmers strongly feel artificial state boundaries have fragmented many water courses and has led to inefficient (Rajasthan, Haryana, Pakistan) water system management practices.

4. Participatory Irrigation Management (PIM)

178. Community of stakeholders are closely knit with each other and understand each others' interests and challenges well as they are in close interaction through current institutional network. Farmers directly communicate with junior engineers working in the field. Agriculture department focuses on crop variety, cropping technique etc. While canal irrigation department is in charge of supply of surface water, ground water is withdrawn at private initiative in an open access system i.e without any defined guidelines for extraction, use, recharge. Water balance -supply and use is fully managed and recorded for canal based surface water while ground water balance is not recorded and managed formally. For canal water shareholders and water use data records are available. Division level executive engineer can get demand data. Agriculture department has some information on tube well data. BBMB collects rainfall and runoff data.

179. Irrigation water management system (formal as well as informal) try to solve the water allocation at the farm level. Land holding size and not cropping pattern dominates the formal water distribution system designed in top down framework. But informal system which is mostly market demand driven the farm level management is cropping pattern driven and land holding size driven. People are happy with formal 'warabandi' system in irrigation water management but not with quantity of water being distributed.

- In water allocation as it is an automatic improvement of historically practiced Mir bandi system in Punjab so people are used to traditional knowledge and proud of cultural heritage. It is equitable as is proportional to landholding and dependent on crop specific water requirement.
- In dispute resolution farmers prefer involvement of third party -government designated officer. Third party role minimizes nepotism and probability of social conflicts. Institutionalisation in this direction has improved social cohesion among farmers. Past incidents of crime/murder on water disputes under villager managed barabandi system is recalled by almost all in all the villages surveyed as undesirable institutional arrangement.
- Informal water distribution system runs parallel to formal surface water distribution system with water pump owners dominating the market with a price announced bilaterally.

5. Challenges in drinking water

180. Drinking water is distributed through piped network managed by government. Sources are both from treated ground water and untreated canal water (at the tail end). But mostly it is from ground water. The primary sources for 90% of the villages are served with piped supply of water. If any household is not enjoying house connection for piped drinking water, then it uses the community connections (public stand-posts) for obtaining drinking water. Secondary sources are private boreholes based ground water for drinking is used for drinking when the piped water is not available.

181. Problems with Quality of Drinking Water; 100% respondents during PRA and household survey report water quality problem. High levels of Fluorides and in some places arsenic contamination is being reported. Fluoride causes yellow teeth and damages teeth and bones. Arsenic is reported to have cancerous effect. Treatment of Ground water for salinity, fluoride, arsenic and silt in tail in surface water for drinking purpose has been demanded.

182. There is divergence in views of stakeholders. Govt. officials feel drinking water is not a problem. Government has taken every step to provide safe drinking water. The present system of providing safe drinking water to the population is costly. Some villages have community level RO system for water treatment. This is provided by the government. But the villages without RO system are aware of the benefits in neighbouring villages and have expressed preference for that through contribution of money but the service reciprocation is longer than promised by service provider.

183. Villagers were very vocal regarding drinking water issues. It was felt during PRA that since surface water is distributed free of cost farmers sometimes ignore inefficiencies in the system and in service delivery system. Whereas, drinking water service delivery system has direct financial commitment of the water users and latter thus monitor the reliability in service delivery more carefully. While in irrigation water service delivery system water users behave more like beneficiaries while in drinking water service delivery system water users behave like purchaser of service conscious of costs and benefits more explicitly.

6. Challenges in agriculture sector: crop choice and farming practice

184. State wide the farmers' choice for scaling up of shift to paddy (all year long some with vegetables/mustard) cultivation has happened due to planned systemic change through policy intervention in late sixties /early seventies. There was a regime change in Punjab farming practice through technological and policy innovation. Technical innovation through introduction of full mechanization in tillage, rural electrification, introduction of electric pumpset, provision of canal water and improved seed variety were introduced as an integrated package to revolutionise /bring in transformative change in farm practices as experiment to provide food security to the nation. Farmers with whom this niche experiment started got full subsidy on inputs to go for crop choice change and were assured of market return from paddy and wheat cultivation through market support price.

185. So both policy innovation and technological innovation along with training for farmers revolutionized the agricultural system in Punjab. The niches got scaled up over time with demonstrated benefit over cost in short term and also with rising scarcity in availability of agricultural labour. Food security dominated the goal from public policy perspective while profitability and higher income motivated the farmers.

186. Support price for paddy insures against farmer's income fluctuation and it's short duration allows higher cropping intensity which could lead to enhancement in farm income . Wheat is also having support price. So such market incentives have attracted farmers towards paddy and wheat cultivation. Whatever cotton cultivation still remains is mainly due to scanty monsoon rainfall pattern and non availability of quality ground water.

187. Current scenario has changed. It is the changed cropping pattern with sometimes 100% bias in paddy cultivation and wheat cultivation in winter has led to very high demand in water. While paddy needs 5 times more water and wheat 3 times more than cotton. Farming practice is highly mechanized, organic farming practice is very limited, horticultural practice is also very limited due to high gestation period (for orchards at least five years). Some rich progressive farmers in Burjmahma with 110 acres of land area could only afford to try orchard in 10% of the land area. Landholding size is not very large. Ludhinana has relatively smaller land holding size . Of the surveyed households land holding size distribution is shown in Table 28.

Table 28 Land Holding Sizes

Land area	Bathinda	Sangrur	Ludhiana
Up to 5 acres	26%	37%	33%
5 to 10 acres	30%	25%	33%
more than 10 acres	44%	38%	33%

7. Future issues : Perception about Climate Change

188. Future issues have been very interesting identified by the stakeholders based on their perception of changing climatic parameters and rising demand. There is less divergence among stakeholders in this regard. We wanted to know past ten year's perception. Given the presence of stakeholders of varied age group historical past also got reflected in recall based statements.

- Temperature: Cold winter is getting shorter compared to 4-5 month to 1-2 months with adverse impact on winter time wheat production with almost 25% reduction. Yields of grams have decreased substantially
- Rainfall: previously there was about 600 mm of rainfall, now only 400 mm. There are rain guages in district offices and so are monitored and made known to farmers from time to time.
- Erratic rainfall pattern affecting over stressed ground water. There are occurrences of unseasonal rain especially shower in harvest season (November) is affecting yield at maturity. Also decolorizes crops. Weather forecast will not be useful as pre mature harvest will lead to further loss of crops.
- Hail Stones – Earlier hail stones would happen in March. Now the pattern has changed. It occurs in Nov – December. In 2006, 2010 hail stones had severe damaging impact on crops ranging from 25-40%.
- Start Date of Monsoon is observationally getting delayed by 15-20 days
- Drought – Increasing

- Depth of Ground Water increasing by 20-30 ft/yr. This is a major problem for Punjab – 90 out of 132 blocks have been declared dark zone; in the region ground water level was 25 ft in 1974, in 1991-92 it was 15 ft (due to floods in 1988-89) and thereafter it is declining continuously.
- Quality of Ground Water deteriorating as salinity is increasing.
- Access to ground water will worsen as all farmers (due to fragmentation of land due to property sharing rules within joint family system and increase in contract farming landholding size is sometimes smaller) cannot afford to buy and run pump sets and informal water market at a price is emerging putting extra financial burden on farmers for irrigation water.
- Surface Water Availability is not perceptibly changing as the canal water distribution has not changed

189. Indirect impacts that were observed by the communities included:

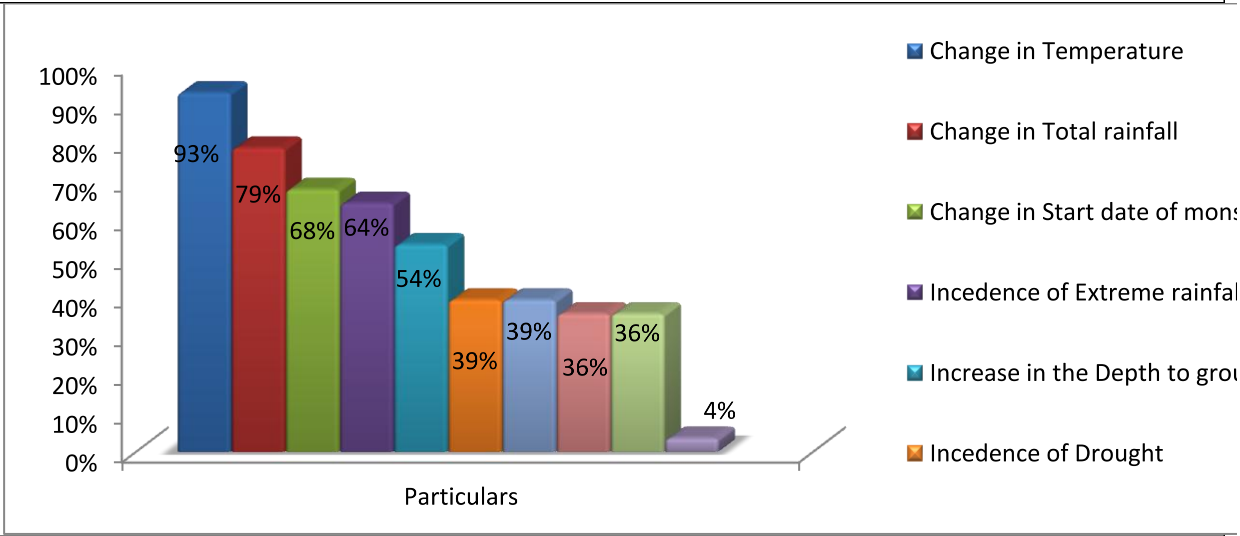
- Overall decreasing yield for crops – also threatens the availability of fodder for animals leading to problems in animal husbandry which provide nonfarm income source from milk production, fishery to limited extent.
- Health Effects might increase with deteriorating water quality. Currently every village has 2-3 cancer patients; poor water is causing bone problem and zinc deficiency (in children).
- Strong demand for Cropping pattern change through policy intervention without affecting farmers' income. There is very strong well articulated consensus among farmers towards transformation of Punjab agriculture. It is articulated that there is need for revolutionary change for crop choice, technological intervention and policy intervention for transforming Punjab agriculture system for provide water security along with food security. This they suggest in line with green revolution of late sixties. If national food security is the goal for Punjab agriculture system then national attention should be more for sustenance of farming practices through appropriate policy support. State administrators feel the action plan need to come from national government.
- General view is if for food security there could be a systemic intervention for water security in late 1960 then a time has now come again for a systemic intervention to save on over extraction of ground water.
- Possible top level political resistance for ground water regulation is expected but bottom up stakeholders are all very positive about innovative solution for conjunctive use of water so long it ensures their water demand.
- With higher access to cheaper and longer hour of electricity ground water extraction will rise as diesel will be replaced to reduce on private cost.
- As on date there is very little incentive for the farmers to continue with agricultural activities. The future generation will possibly not engage in farming. So family level farming practice might be replaced by contractual farming.
- Role of Women in farming activity has reduced after mechanization. There is less economic liberty in society .
- There is growing indebtedness among farmers not always for agricultural production related loans but for other social reasons.
- Variation in responses across three surveyed locations are shown in Figure 48 below

190. Water Management Issues and possible solutions that got very high support from all stakeholders include:

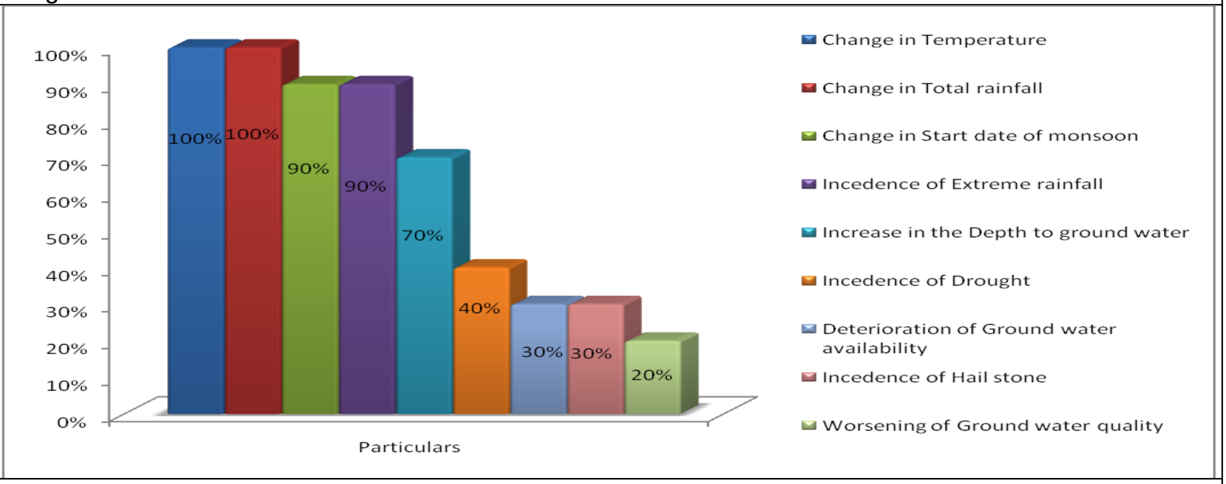
- Conjunctive management of surface and ground water. Need for ground water regulation is understood by all but none could come up with any concrete suggestions. Farmers feel regulation is needed.
- Reduction in paddy cultivation area
- Use of sprinkler/drip for non rice crops

Figure 48 Variation of Responses

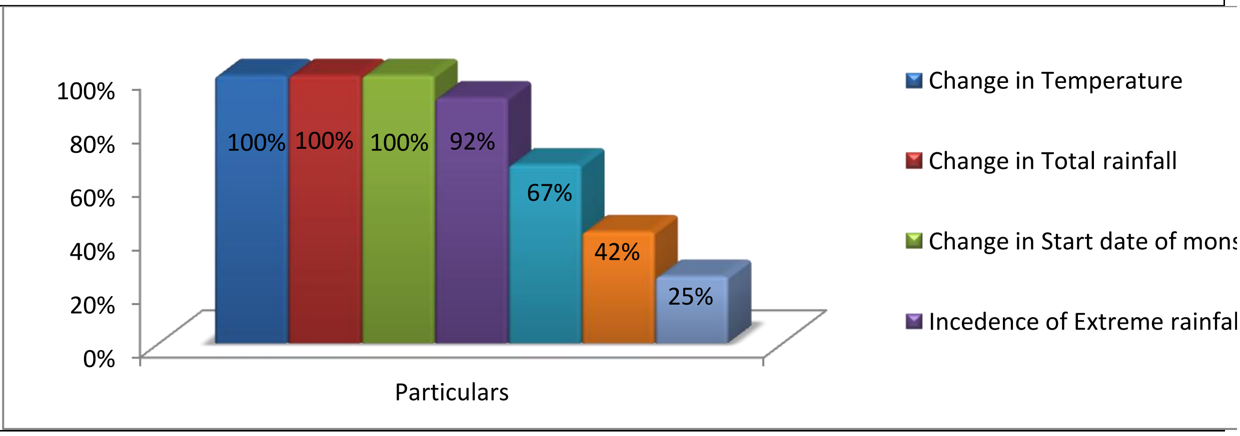
Bathinda



Sangrur



Ludhiana



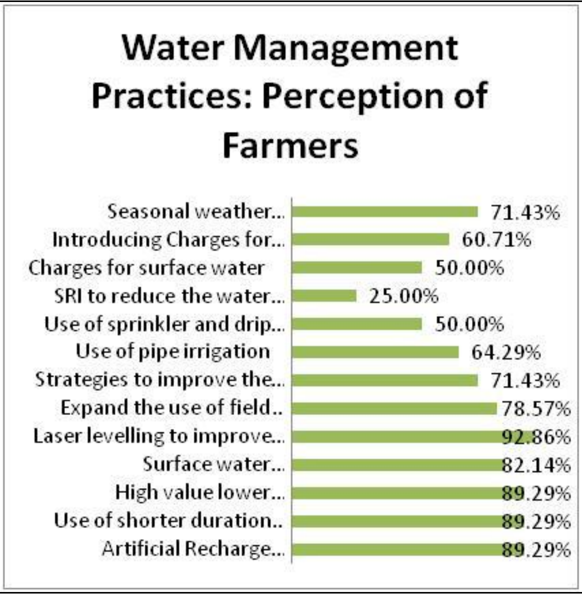
- Lining of unlined canals to enhance water use efficiency
- Laser leveling for on the ground water efficiency

- No single fragmented solution will be useful. A portfolio of actions being recommended. :Conjunctive use with changed cropping pattern and additional support price for non paddy and wheat crops
- More technical assessment needed to understand; feasibility of tanks for irrigation and ground water recharge, Assessment of water carrying capacity of existing canal network needed to understand possibility of using same infrastructure for carrying enhanced water for distribution under conjunctive use regime, Rain water harvesting in roof top due to good housing condition

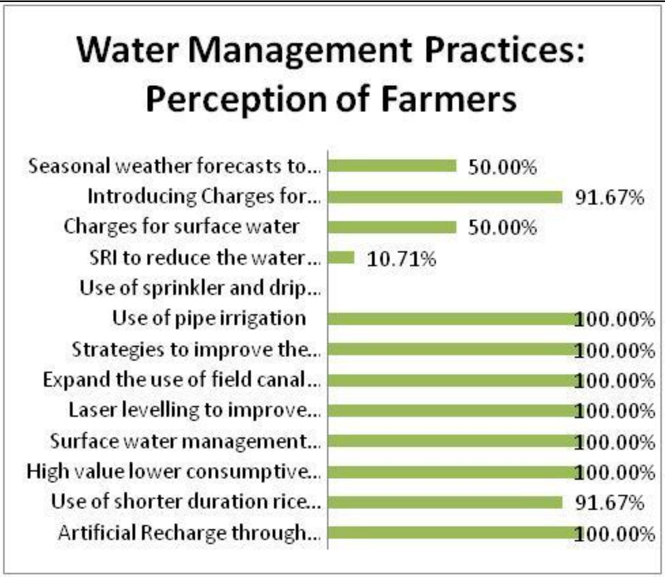
191. District wise need management practices are shown in Figure 49 below.

Figure 49 District Wise Water Management Practices

Bathinda



Ludhiana



8. Possible Mechanisms to Enhance Resilience and Reduce Vulnerability

- Short duration crops, direct seeded paddy cultivation (reduces 3 to 4 irrigation need)/ SRI (experts and farmers do not prefer SRI for Punjab as it is still transplantation technique and is labour intensive), late planting are suggested.
- Government regulation on bore holes number/water withdrawal pattern. Farmers suggested control on bore hole number. Because they could visualize water metering as only means to control extraction and are thus not supportive as one earlier attempt failed in Sangrur. But the 100% of the farmers interviewed were skeptic about top level politica
- l will because of latter’s myopic vision.
- In Bathinda government ownership of ground water for distribution may be acceptable only if adequate water supply is assured. Canal managers see as a very good possibility but need for prior assessment of canal capacity, how to do it at outlet point or alternatives. Need for serious technical feasibility assessment. Framers want 100% water supply security. However, in Ludhiana government ownership on ground water was supported at all. In Sangrur farmers were not supportive of government intervention. The higher the water stress level control was favoured.
- Water associations are weak and needs to be strengthened. Need is expressed more by progressive farmers in Bathinda.
- Crop diversification through regulation: cotton, sugarcane, horticulture. 100% farmers want but with more knowledge support for other crops as they understand paddy is unsustainable anyway.
- Minimum support price for additional crops other than paddy and wheat, on short duration paddy variety. 100% farmers want. Farmers in various places are trying out less water intensive crops like pulses, potato, maintaining cotton , sugarcane, orchard but market

fluctuation is making their income uncertain so not many farmers are changing cropping pattern.

- Zoning/landuse pattern under various crops through regulation
- Subsidy on electricity is not an issue rather farmers are interested in subsidy on other inputs which is leading to cost escalation and interested in direct subsidy coming to farmers.
- Training and Subsidy on sprinkler and drip irrigation. Must be taken up as national scale movement.
- 100% farmers want subsidy on laser leveling as well. Subsidy on water moisture meter, tensometer, direct seed drilling machines are suggested.
- Replacement of diesel pump sets and rural mobility by bio fuel with appropriate incentive /subsidy as that will yield multiple benefits-change cropping pattern, water use, diesel use, electricity use.
- Since water is anyway required, even if the govt. introduces charges on electricity, the farmers will have to pay to use electricity or will substitute by diesel. Farmers feel as on date there is no direct benefit from the “free” electricity (or water). While calculating the MSP, the authorities make an allowance for the free water and electricity and adjusts the MSP downwards. So basically farmers are not happy with electricity subsidy system. The electricity charges are not metered rather based on HP of motors and allegation of corruption on charge collection is reported by the farmers.
- Farmers feel Erratic power situation is leading to inefficiency in irrigation practice because of uncertainty in water supply timings. Demand is not for more power but for reliable supply.

9. Capacity Building, Training Needs and Recommendations

- There is general awareness but this will not be enough to bring in desired directional changes
- There is need for awareness building about need for water resource allocation for maintaining ecological and environmental flow
- It is important to prepare community for impending changes in natural events and possible changes in response strategies to enhance compliance to policy changes, new technology adoption, new farming practice adoption, resource use pattern shifts etc.
- Based on assessment of responses and situation analysis it is felt that there is need for at least few years (may be through twelfth five year plan starting in 2012) of well planned capacity building and training need at all levels of stakeholders. Following training needs are identified:
- To enable ground water regulation implementable it is important that community be made aware of possible efficient management practices suggested for open access and common property resource, role and advantages of communities in managing open access resources. Need for more active community participation to protect ground water resources for ensuring sustainable future. Training needs to focus on case studies and examples from various countries on ground water regulations and variety of institutional arrangements in practice with success and failure stories to sensitize community of their possible active role. It can improve future community participation in regulation of ground water for conjunctive use, emergence of water users association. Otherwise there may be resentments from various quarters due to lack of information and knowledge.
- To bring in behaviourial changes alternative strategies with associated costs and benefits be made clear to the farmers. Crop change patterns and their impacts on water and income be made clear. If water use demand do not change through cropping pattern change etc. , then there will be cost involved in getting better ground water quality through investment in deslinasation etc. The efforts need to start now both to educate the community on possible technological options available and practices in other water stressed countries/states. To build awareness about value of good quality water and to prepare mind set towards need for payment for water service charges to ensure quality and quantity in a sustainable manner.
- Such trainings should not be planned for only one time dose. Rather they need to be planned in such a way so that local universities, research institutes, administrators training institutes can conduct them on regular basis for water managers, engineers, agriculture extension officers, farmers, water users associations.
- Awareness generation among water users and suppliers about rights and duties in beneficiary role and customer/purchaser role to strengthen decision making process for either category of stakeholder. With rising water stress water service charge will become imperative. There is lack of political will due to perceptive loss of support from water users as most like to see

water as right. Rising scarcity will make it necessary to shift from right based policies to incentive based polices. There is need for community preparedness building through quality knowledge and information dissemination.

- Training for farmers to allocate time for non farm activities is suggested mostly in Bathinda District.
- Need and role of water users association for social mobilization. Progressive farmers in Bathinda district are very much in favour of water users association and they themselves are organizing seminars for farmers by inviting experts.
- For all training appropriate reading materials and training modules are to be prepared.
- Training is needed to motivate people to see the benefits in moving out of subsidy system to payment for eco service payment based system.

192. Based on assessment of community response and secondary literature (Heera et al 2004, Jeevandas et al 2008) it is clear that a Strategic Plan needs to aim at providing micro level livelihood/income and macro level productivity security/risk minimization through a portfolio of measures . No single action can ensure adequate adaptive capacity. Simultaneous implementation of portfolio of actions might bring in desired radical change. The portfolio of actions can range over a number of spaces:

- Crop diversification at farm level
- Crop zoning at state level
- Restrictions on paddy cultivation
- Marketing facility for vegetables, new crops, market support price for crops other than paddy and wheat, promotion of horticulture practice, oil seed, sugarcane
- Alternative irrigation techniques
- Use of moisture meter, laser leveling for optimizing irrigation practice
- Use of SRI/Direct seeded rice, shorter duration rice variety
- Ground water recharge
- Water quality management
- Water course lining
- Managed conjunctive water use
- Water use monitoring by ground water permit system /bore hole restrictions/ground water use regulation/reliable electric supply/rationalization of surface water supply/payment for eco service
- Improved Weather forecast
- Enhancement of non farm income sources
- Possible revival of old ponds/tanks
- Farmers training regarding the optimum use of water for improving overall water situation

10. Road Map

193. The road for implementation of strategic plan need an Integrated approach

- through water use and supply information base creation. This can bring the roles of the stakeholders together observationally. Current level of information scattered across different departments cannot lead to integrated approach on cross cutting issues.
- Top down plan needs to be cross checked through bottom up response to make the plan inclusive. In Bathinda district as well as in Sangrur farmers appreciated the PRA process as it could bring in farmers of various landholding size together and provided space for discussion on a common issue. In Ludhiana some discontent on surface water distribution system emerged. So how this platform for free discussion between top and bottom level stakeholders can continue needs to be planned and included in strategic plan preparation as an integral action plan.
- How to bridge the gap in knowledge about thinking process of policy maker and farmers' response strategies on common issue of statewide water stress need better coordination. This will enable cooperation building between farmer and policy maker. This alone can ensure participatory solution to the common problem.
- Farmers' preparedness for changing their cropping pattern choice and associated conditionalities need to reach policy makers table to give latter confidence and directions for possible policy changes. How to institutionalize this needs further probe.

- How informal ground water market can be transformed into formal participatory water management system needs to be explored further through research and subsequent consultation with the stakeholders.
- What combination of actions in strategic risk minimizing policy portfolio be included for various districts need to be checked through simple cost benefit analysis and further stakeholder consultation.
- Subsidy versus PES as strategic policy instrument needs further community consultation.
- How IWRM institution can work towards formalizing informal ground market needs further check.
- What can be the contribution of changes in technology, policy and behavior of farmers needs an assessment.

C. Summary of Select Household Survey

194. The summary of the select household surveys are shown in Table 29 to Table 32.

Table 29 Household Surveys Groundwater

Ground water availability

		Wet			Dry		
		<5m	5m-30m	>30m	<5m	5m-30m	>30m
Bhatinda hh-25	poor	8.00%			4.00%		
	medium		4.00%	8.00%		4.00%	8.00%
	good		8.00%	44.00%		8.00%	44.00%
Sangrur hh-10	poor						
	medium					10.00%	10.00%
	good		10.00%	80.00%			70.00%
Ludhiana hh-12	poor						
	medium						
	good		25.00%	30.00%		25.00%	75.00%

Ground water quality

		Wet			Dry		
		<5m	5m-30m	>30m	<5m	5m-30m	>30m
Bhatinda hh-25	poor	8.00%	8.00%		4.00%		
	medium		8.00%	12.00%		12.00%	8.00%
	good		4.00%	44.00%		4.00%	44.00%
Sangrur hh-10	poor						
	medium		10.00%			10.00%	
	good			90.00%			90.00%
Ludhiana hh-12	poor						
	medium						
	good		25.00%	30.00%		25.00%	75.00%

Table 30 Household Surveys Irrigation

Source of Irrigation water demand as reported by households

		Households reporting for Wet season				Households reporting for Dry season			
	% of total demand	canal	<5m	5m-30m	>30m	canal	<5m	5m-30m	>30m
Bathinda 25	<31%	48.00%			4.00%	20.00%		8.00%	16.00%
	30%-60%	16.00%			24.00%	12.00%			12.00%
	>60%	16.00%	8.00%	4.00%	24.00%	32.00%			16.00%
Sangrur 10	<31%	70.00%			10.00%	70.00%		10.00%	
	30%-60%								
	>60%			10.00%	50.00%				60.00%
Ludhiana 12	<31%	100.00%				16.67%			
	30%-60%								
	>60%			25.00%	66.67%			25.00%	75.00%

Table 31 Household Surveys Changes in Last 10 years

What changes have been observed over the last 10 years

Location /nr respondants	Particulars	No change	Minor change	Significant change
Bhatinda 25	Temperature	8.00%	64.00%	24.00%
	Total rainfall	8.00%	72.00%	12.00%
	Extreme rainfall	8.00%	60.00%	8.00%
	Hail stone	52.00%	36.00%	
	Start date of monsoon	8.00%	56.00%	8.00%
	Drought	64.00%	20.00%	8.00%
	Surface water availability	76.00%	4.00%	4.00%
	Depth to ground water	40.00%	16.00%	24.00%
	Ground water availability	40.00%	16.00%	8.00%
	Ground water quality	60.00%	20.00%	12.00%
	Flood	32.00%		
Sangrur 10	Temperature		100.00%	
	Total rainfall	10.00%	90.00%	
	Extreme rainfall	40.00%	30.00%	
	Hail stone	60.00%	30.00%	
	Start date of monsoon		80.00%	10.00%
	Drought	100.00%		
	Surface water availability	70.00%	10.00%	
	Depth to ground water		70.00%	30.00%
	Ground water availability	30.00%	60.00%	10.00%
	Ground water quality	60.00%	40.00%	
	Flood	30.00%		
Ludhiana 12	Temperature		50.00%	50.00%
	Total rainfall		83.33%	16.67%
	Extreme rainfall	25.00%	66.67%	
	Hail stone	50.00%	41.67%	
	Start date of monsoon		58.33%	33.33%
	Drought	100.00%		
	Surface water availability	75.00%		
	Depth to ground water		50.00%	50.00%
	Ground water availability	50.00%		25.00%
	Ground water quality	100.00%		
	Flood	33.33%		

		Wet months		
	Sources	Primary source	Secondary source	Primary source
Bhatinda 25	Spring			
	Bore-hole Hand Pump	16.00%	36.00%	12.00%
	Bore-hole Electric Pump	16.00%	16.00%	8.00%
	Dug Well			
	Piped-supply House Connection	24.00%	20.00%	16.00%
	Piped Supply stand Pipe	8.00%		8.00%
	Canal	44.00%	8.00%	36.00%
Sangrur 10	Spring			
	Bore-hole Hand Pump		10.00%	
	Bore-hole Electric Pump	10.00%	30.00%	10.00%
	Dug Well			
	Piped-supply House Connection	80.00%		70.00%
	Piped Supply stand Pipe			
	Canal			
Ludhiana 12	Spring			
	Bore-hole Hand Pump	41.67%	33.33%	41.67%
	Bore-hole Electric Pump	58.33%		33.33%
	Dug Well			
	Piped-supply House Connection		91.67%	8.33%
	Piped Supply stand Pipe			

Table 32 Possible Methods to Improve Efficiencies

Possible methods to improve water efficiencies as a means to conserve water

	Bathinda 25					Sangrur 10					Ludhiana 12				
Methods	Very Supportive	Supportive	Mixed	Do not Support	Against	Very Supportive	Supportive	Mixed	Do not Support	Against	Very Supportive	Supportive	Mixed	Do not Support	Against
Improve the artificial through community participation and incentives	68	12				90	10				17	83%			
Promote the use of shorter duration rice varities	76	8	4			70	30				50	42			
Promotion of high value lower consumptive crops to replace rice	52	24				80	20				25	75			
Improve the surface water management and systems of water allocations	40	16				50	50								
Expand the use of laser levelling to improve efficiencies	56	32				40	60				42	58			
Expand the use of field canal lining	44	20				40	60				33%	67			
Develop strategies to improve the conjunctive use of surface and groundwater	4	28				30	70				17	83			
Develop the use of pipe irrigation	4	20				20	80								
To reduce water losses develop the use of sprinkler od drip irrigation	16	20	4	32	4		50		20	###				100	
Promote the use of SRI to reduce the water demand of the rice crop	8	8		16			20		30			25		42	8
Introduce increased charges for surface water against increase in service delivery of water and support for improved irrigation systems	16	28		16	12		50		30	###		50		25	25
Introduce some level charges for electric power for tubewells in return for improve electricity availability and subsidies to reduce water losses	28	36	4				50		40	###	8	83		8	
Seasonal weather forecasts to be provided for farmers	56	28	4			50	50				33	17		50	

VII. INSTITUTIONS

A. Introduction

195. The National Action Plan on Climate Change document includes National Mission on Water which addresses the issue related to water in the context of climate change. One of the key strategies advocated is the promotion of basin level integrated water resource management. Mainstreaming of climate change, refers to integration of current and future climate change vulnerabilities or adaptation into government policy and implementation levels. The role of institutions and the enabling environment like policies, laws, acts, and regulation are critical to ensure adaptation responses to climate change impact in general and on water sector in particular.

196. The Punjab State ***Water Policy*** came into being in May 1997 on the lines of National Water Policy 2002 consequent to the emergence of number of issues and challenges in the development and management of the water resources. The State Water Policy envisions that available water resources should be utilized efficiently and judiciously to meet drinking water needs and irrigation requirements.

197. The key features of the policy among others are to a) ensure a judicious and equitable distribution and efficient use of available water resources by different sectors b) develop all utilizable water resources to the maximum possible extent, including surface water (both internal and external), groundwater and waste water for equitable economic development and social well-being after properly identifying the suitable source of water and the quality of water required for different sectors c) treat the problems of rising water table/water logging and salinity/quality of water resources, which deserve special treatment with appropriate technology d) promote and encourage participation of beneficiaries, Panchayati Raj Institutions (PRIs), Municipal Bodies, NGOs and the private sector in all areas of water development, planning, operation and management e) promote awareness about the need for conservation water f) encourage application of Improved Modern Irrigation Technologies, particularly sprinkler and drip irrigation, on-farm management practices & proper technology transfer to increase water use efficiency & crop production The policy accords for Drinking water, Ecology, Irrigation, Hydro-power, Thermal power, Agro-Industry, Other Industries and other uses.

198. Although Punjab has a clear Water Policy, problems continue within the water sector namely a) There is no agency dedicated to water resources management providing properly functioning regulatory services to equitably share resources and to protect the common property for environmental and social uses. In Punjab the need for water resource management are broadly defined around Surface Water, Groundwater and the water uses mainly agriculture but also potable water, industry and environment. The inherent difficulties (organisational. legsilative, and provedural types) in managing water resources in the state is that the surface water is under Government whereas groundwater and agriculture is under private sectors and these could be called as organizational.

199. The legislative and procedural problems are a) Water management is based around the surface water systems b) there is no organizational system to look at the combined resources and conjunctive water management c) The "centralized" warabandi water management is designed for equitable allocation of the water but does not incorporate any consideration of crop water needs nor any form of integrated management of the surface and groundwater resources and it has remained more a prescriptive than a negotiated institutional arrangement***.***

200. Regulations: Without good ***regulation*** it is not possible to maximize the economic and social benefits resulting from water use in an equitable manner. Good water resource regulation requires an enabling environment which ensures the rights and assets of all stakeholders and also protect public assets such as intrinsic environmental values. In Punjab the imposition of regulation is very sensitive and although some soft regulation is being taken up, the more radical measures are not considered appropriate. The enabling environment to put regulatory measures is determined mostly by national, state and local policies. Legislation, that a) create a foundation for the negotiation of water management arrangements and b) enable all stakeholders to play their respective roles in the development and management of water resources, is hardly in place.

201. **Acts:** With regard to surface water**,** existing rules still derive from the early common rule of riparian rights. Thus, the basic rule was that riparian owners had a right to use the water of a Streamflowing past their land equally with other riparian owners, to have the water come to them undiminished in flow, quantity or quality. In recent times, the riparian right theory has increasingly been questioned as the appropriate basis for adjudicating water claims. Further, common law or rights must be understood in the context of the recognition that water is a public trust. If the latter principle is effectively applied in the future, it would have important impacts on the type of rights and privileges that can be claimed over surface water.

202. As for as ground water is concerned, Punjab is not in favor of ground water regulation as it is felt that such a regulation will create a hardship to its farmers. However, in order to minimize its over extraction, willing to adopt different measures such are a) large scale artificial recharge b) modification in cultivation practices like sowing of paddy after mid June so as to decrease evaporation c) Conforming to controlled, regulated and metered electricity supply d) promotion of micro irrigation e) crop diversification through guaranteed minimum price support and encouraging industries. The other measure includes banning of tubewells completely and restricting the energy power to 10 HP so that deeper aquifers are spared from exploitation

203. **PIM act**: The Punjab Govt. has informed that since they feel that a separate PIM Act is not needed action is being initiated to amend the Northern Canal and Drainage act VIII of 1873 to enable smooth functioning of WUAs wherever it exists.

204. **Institutions:** Water Resources Organization is primarily entrusted with Research and development activities relating to ground water surface water and various watersheds. The main objective of Water Resources Organization is to carry out the ground water and surface water studies for formulations of various schemes and policy matters for the judicious use of Water Resources in Punjab State. It came into existence in the year 1970 when a directorate was set up for carrying out explorations for Water Resources. Various activities being undertaken since then and are presented in in Table 33 in addition to the responsibilities and functions as carried out by other departments in Punjab.

Table 33 Responsibilities of Departments

Sl.No	Institutions	Responsibilities
1	Water Resource Department (WRD)	<u>Ground Water related activities</u> Ground Water monitoring Collection of rainfall data Collection of ground water & soil quality data Preparation of various maps such as ground water depth maps, long term rise and fall of water level fluctuation maps Carrying out hydrological, hydro-geological, hydro-chemical, geophysical, mathematical, statistical, agronomical, remote sensing and other studies. Deep ground water investigations to identify aquifer parameters Dynamic Ground Water Estimation depicting the stage of development of ground water resources. Maintaining data base for ground water Framing of policy matters like ground water legislations and State Water Policy Surface Water related activities: Up gradation of hydro meteorological network in Punjab State Up gradation of discharge observation sites Maintaining data base for surface water Planning and Design Directorate located at Chandigarh undertakes all these activities. Plus also undertakes watershed activities in select areas of Punjab

2	Punjab State Tube well corporation Ltd	Sinking and installation of direct Irrigation and augmentation Tubewells. To undertaken installation and construction of Tube well and other connected works on behalf of private individuals/bodies/Govt. institutions, Companies. To engage processing manufacture and sale of Tube well equipment, accessories, Spare parts machinery, plants or any other commercial or industrial products connected therewith To set up and maintain laboratory/workshop to provide technical guidance repair facilities, sale of stores, concerned Tube well Irrigation Projects To provide Tube well equipment or plant land machinery on rental basis to any individual/body or Govt. Department To carry out all kinds of ground water exploration business to quantify the ground water resource in different areas
6	Panchayat & Rural Development Department	Construction, repair and maintenance of community assets like sanitation and drains; wells, water-pumps, springs, ponds and tanks for the supply of water for drinking, washing and bathing; ponds for animals, supply of water for domestic use and for cattle; Promotion and development of Agriculture and horticulture; Promotion and development of fisheries in the village. Planting and preservation of trees on the sides of roads and other public lands under its control; Fuel plantations and fodder development.
8	Agriculture Department	Monitoring the supply and quality of Agricultural inputs like seeds, fertilizers, pesticides, irrigation water and machinery & equipments etc.. Promotion of Resource Conservation Technologies (RCT) for NRM To promote judicious use of irrigation water through better on farm water management and to monitor the water level behavior and its quality.
12	State Pollution Control Board	to scrutinize applications for consent under the Water Act, 1974 and the Air Act, 1981 as received from the industrial units and local bodies to scrutinize applications for the authorization under the Hazardous Wastes To scrutinize applications for no objection certificates from pollution angle to the new industrial units. To vet the designs of effluent treatment plants and air pollution control proposals received from the industries. To co-ordinate with other cells within the Board for laboratory back up and monitoring of treatment plant performance. to scrutinize the proposals received from the Regional Offices of the Board for launching prosecutions against the defaulting industrial units and the local bodies both under the Water Act, 1974 and Air Act, 1981 and other Rules framed under Environment (Protection) Act, 1986. To prepare cases for initiating legal action under the Environment (Protection) Act, 1986.
13	Department of Environment	Environment Education Training & Information Institutional Support & Public Participation Research and Development Protection & Conservation of Resources
14	Department of Soil & Water Conservation	Conservation of Irrigation Water Increasing Water Application Efficiency In-situ Moisture conservation Ground Water Recharge Micro Water Resource Development Consumptive Use of brackish water & sweet water Micro Irrigation- Drip, Micro-sprinkler, Sprinkler Irrigation Reclamation of degraded soils Human Resource Development Training & Extension

205. **An assessment of Institutions:** Sectoral/departmental, isolated, unplanned approach restrain their potentials to explore answer to some of the critical questions challenging the institutional changes/ role transformation within the sectoral departments in general and water resource departments in particular and especially the questions like a) which are the key factors that motivate these institutional changes? b) What are the nature and direction of these changes? c) How adequate are these changes for addressing both the existing and emerging water sector challenges? and d) what do they ultimately mean for overall water sector performance? and these questions are yet to be

responded to. Further, an overview of the main institutional mechanism for state-level planning and management of water resources indicates that a) there is a lack of conjunctive planning and regulation of surface and ground water b) poor understanding of the conjunctive water balance systems c) water quality data is monitored but not linked planning and management and d) artificial recharge is important but not incorporated into the overall water resource planning and finally all the agencies see their responsibility as **developing water resources** for the public good.

206. But what has become important in the change in context is that Water agencies also need to consider non-water issues, such as environment, equity and social. Water governance is needed to implement public policies for sustainable water investments and management with support of society.

207. Conclusions: What one could infer from a quick review of policies, acts and functions of various departments is the lack of coherence between water laws, policies, water administration processes and procedures for ensuring good water governance as an enabling environment for adopting IWRM in a select basin as a tool for adaptation. one could say that any sound policy, acts and mandates of water centric institutions aiming at water resource development and management should recognize in its totality a) **Information Systems and Resource Planning** to provide much needed information about groundwater availability, quality and withdrawal, etc., for use by planners and for the purposes of monitoring and further research b) **Demand-Side Management** for regulating groundwater withdrawals at sustainable levels and such mechanisms to include, for example, licenses, laws, pricing systems, use of complementary water sources and water-saving crop-production technologies (**In conformity with IWRM principles) c) Supply-Side Management to augment** Groundwater recharge by means of mass rainwater harvesting and recharge activities and to maximize surface water use for recharge and the introduction of incentives for water conservation and artificial recharge d) **Groundwater Management in a River Basin Context** to maximize efficiency and the focus of interventions could be expanded (from a very 'local' level to the level of entire river basins.

B. Bhakra Beas Management Board (BBMB)

208. The Bhakra Beas Management Board is dedicated is engaged in regulation of the supply of Water & Power from Bhakra Nangal and Beas Projects to the states of Punjab, Haryana, Rajasthan, Himachal Pradesh, Delhi and Chandigarh. The BBMB directly manages the installed capacity of 2804 at Bhakra, transmission of power in the Northern Grid through a wide network of 3735 KM of 400 KV, 220 KV, 132 KV and 66 KV transmission lines and maintenance of the Bhakra and Pong Dams and also operates long Hydro tunnels and Hydel channels.

209. The functions include, Administration, Operation & Maintenance of Bhakra-Nangal Project, Beas Project Unit-I (Beas Sutlej Link Project) and Beas Project Unit- II (Pong Dam) in Northern India and regulation of supply of water from Sutlej, Ravi and Beas to the States of Punjab, Haryana and Rajasthan. The Board also regulates the supply of power generated from Bhakra-Nangal and Beas Projects. The BBMB also aims to:

- To setup appropriate environmental objects, targets and their achievements as per Environment Management Plan (EMP)
- To undertake the studies for implementation of NEERI Report for safe disposal of silt from BSL Project
- Setting up of fully equipped central laboratories at all project stations for conducting silt analysis, chemical and bacteriological tests for checking the performance of potable water, treatment plants, sewage treatment plants etc.
- To prepare 'Catchment Area Treatment' and 'Fringe Area Treatment' plans and to implement the plans in coordination with H.P. Government Authorities
- BBMB and IMD co owns some of the rain gauge stations; others are owned by HPPCL, irrigation departments and CWC

210. The role of the board is quite wide and includes, energy generation, and management support to the partner states and allocation of and management of water between the states. The percentage of sharing of the water between Punjab is 58 %, Haryana 32% and Rajasthan 10%.

211. The BBMB is in the process of setting up Real time Data Support System (RTDSS) for better management of reservoir. The RTDSS will be backed up state of the art real time data acquisition (DAS) most of which will be installed in Himachal Pradesh. The system will be based on an major upgrade and extension of the present manual system. For the Sutlej an MOU of data sharing between the different hydropower producers has been obtained. The BBMB will conduct analysis of the data including modelling including rainfall runoff modelling, snow melt runoff modelling, snowmelt forecast modelling and inflow forecast modelling etc. Weather forecast modelling (short medium and long range will be obtained by BBMB from the national Centre for Medium Term Forecasting in Noida (NCMRWF). The forecast by received from NCMRWF will be input into various models which will provide inflows estimates in the Sutlej and Beas rivers. Based on these analysis the RT-DSS will provide flood forecast for the Beas and Sutlej rivers which will be of significant importance to the Bhakra reservoir operations as well advance information of pending floods which can be used by the hydropower producers and local administrations to support timely action against floods. These data are to be shared among various members. There are 9 members on the board which meets every month.

212. It is understood that BBMB operates a complicated procedure for water storage and allocation between the states as some portion of the water is snow melt and others are dependent on rainfall. There are two distinct period for water supplies: 21st September to 20th June known as the depleting period and 21st may to 20th September the filling period.

213. BBMB potentially can play an important role in supporting the management of the Sutlej river. It however has some conflicts of interest that need to be addressed being both a resource manager as well as an operator.

C. Water resources information

214. A key recommendation of the National Water Mission is to develop water information systems. A water resources database has been prepared for the Sutlej basin to support the project objectives. Data has been sourced from the CWC, CGWB, IMD, the Punjab Irrigation Department, and IITM Pune. Data were requested from BBMB, but as yet have not been received. The CWC released its web based Water Resources Information System (WRIS) in November 2010. The India-WRIS project was a joint venture between the CWC and the Indian Space Research Organisation. Project details may be found at: http://www.india-wris.nrsc.gov.in/. Details have been provided in the Strategic Framework report. CWC have proved a series of layers from WRIS and these provide the mapping base.

215. The State of Punjab participates in the HP-2, as does CWC. CWC have provided data for a number of surface water stations on the Sutlej, and these have been used in preliminary analysis. The Punjab Water and Environment Directorate is a participating agency in HP-2, and has a focus on groundwater. The Groundwater Board was abolished in Punjab in 1997, and the Water and Environment Directorate liaise directly with the CGWB. Surface water monitoring in Punjab is handled through the surface water section of the Punjab Irrigation Department, who also participate in HP-2. The Irrigation Department has recently purchased GIS software, but at present records are paper based.

216. The Agriculture Department completed census of tubewells in 2001 and 2007, recording information such as the number of wells, discharge, depth etc. The Agriculture Department has also been conducting trial on different cropping systems, including low much cropping and rice intensification. The State Remote Sensing Centre in Ludhiana has developed a number of layers of relevance to water resources development and planning in Punjab. Visits have yet to be made to the Agriculture Department and to the Remote Sensing Centre. These will be undertaken in March when a more complete picture of data availability will be obtained.

Appendix 2B Lower Sutlej Sub Basin Punjab

Strategic Framework Plan

Appendix 2B Strategic Framework Plan

VIII. INTRODUCTION

A. Approach

219. Water management has always been a challenge. There is no clear evidence that for the Punjab the current management and use of water is sustainable. The development policies now have to change from the prevailing management philosophy of large scale infrastructure, to meet current and projected demands through improved efficiencies and management. There is now evidence that climate change effects are already occurring and some preliminary estimates of the likely changes are presented. Four broad direction towards long term and sustainable water management are; (i) rethink assumptions and definitions about water supply; (ii) work to reduce demand by conservation and efficiency; (iii) develop improved management systems; and (iv) incorporate climate change into all water decision making.

B. Summary of Key Issues

220. The major existing water issues in lower Sutlej Basin are (i) over exploitation of ground water and falling ground water table; (ii) water logging and salinity in the south west and (iii) ground water quality issues. The dynamic ground water regime in basin is under significant stress and abstractions are rapidly expanding despite incremental costs of extraction from greater depths than in previous years. Ground water abstractions are of the order of 31 BCM as against annual groundwater availability of 21 BCM. There are ongoing programmes to support recharge however it is considered the viable potential is quite limited. Sustainable management of surface water and groundwater will require new initiatives to conserve water and conjunctive management of the ground and surface water . A summary of the main issues and effects is given in Table 34

Table 34 Summary of Main Issues

<table>
<tr><td>North –East Zone</td><td>Deep water table & high pumping lift
Soil erosion
Selenium toxicity in localized area (0.25-69.5mg/l)</td></tr>
<tr><td>North Central Zone</td><td>Groundwater table decline due to over –use of groundwater
High Residual Sodium Carbonate and EC value in groundwater</td></tr>
<tr><td>South west Zone</td><td>Erratic & Scanty rainfall
Brackish groundwater
High levels of Arsenic in groundwater in some located areas
Water Logging and salinity</td></tr>
<tr><td colspan="2">Overall Effects</td></tr>
<tr><td colspan="2">Groundwater level is in decline
Very low surface water duties
Rice and wheat offer secure prices and preferred by farmers
Farmers are required to deepen the wells & lowering of pumps to greater depths to maintain yields
Drilling of new wells by farmers to greater depths beyond lift of centrifugal pumps
Replacing of shallow depth pumps by deep expensive submersible pumps with farmer’s own resources.
Increase is the incremental cost of groundwater extraction /cost of well deepening and even well replacement and water quality degradation.</td></tr>
</table>

IX. STRATEGIES TO ADDRESS CURRENT ISSUES

A. Strategy for Adaptation Planning

221. The application of climate projections into the development of adaptation planning requires to be cautious and pragmatic. Framework planning for the sub-basins is based on three stages as described below;

222. **Stage 1: Adaptation Strategies for Current Issues**: The lower Sutlej sub basins has very significant levels of present issues that are affecting present efficiencies and long term sustainablities.

The approach will be to develop an initial adaptation plan for present needs based on current climate variabilities. Present issues includes development needs of increasing population, increasing agricultural production and farm incomes.

223. **Stage 2: Viabilities of Adaptation Strategies Against Climate Change Impacts**: The resilience of the 'Adaptation Plans for Present Issues' will be tested against projected climate change impacts. The incorporation of the projected climate changes into the planning will depend on :

- **The level of confidence** of the projections; some projections are more robust than others; for example projections for sea level rise are more robust than rainfall patterns.

- **The type and estimated design** life of any investment -major investments/programmes with long design life require to incorporate climate projections beyond 30 years whereas shorter simpler initiatives can designed to meet present climate variations. Major long term investments based on low levels of projection confidence would be avoided.

- **Scope for flexibility of the adaptation design**; incorporating facilities wherever possible to upgrade adaptation design step by step to meet progressive climate changes.

- **An assessment of the incremental costs** to meet the projected impacts will be made; where incremental costs are low then it these might be factored into the adaptation design whereas major cost implication maybe left out in the interim. The aspects of safety and implications of delayed action would be assessed.

Stage 3: Preparation of a Climate Change Adaptation Framework: Adjustments will be made the Present Issues Planning based on the outputs of the testing under stage 2.

224. This section describes the various possible strategies to address current issues.

B. Farmers Perceptions

225. To understand the issues of the communities a participatory rural appraisal was carried out as discussed in the Sub Basin Profile. The farmers of Sirhind canal system showed that in general they are fully aware of their water and environmental problems. The farmers in Punjab are very enterprising and professional and are adaptable to any new methods and new solutions. The farmers were found to be enthusiastic about various water saving management practices like canal lining, laser land levelling, raised bed planting/ furrow irrigation, minimum disturbance of soil (zero tillage) and ground water recharging practices. They are fully aware that high water demanding rice-wheat cropping system is becoming threat to the ground water resources sustainability, increased depths to groundwater is adding significant costs of the pumps which typically only last a few years; this escalating cost of pumping water from deeper ground water aquifers using submersible pumps is pushing many farmers to difficult financial problems.

226. Farmers were of the opinion that there is no single solution and a portfolio of actions is required. Many farmers are of the view that diversification from rice-wheat cultivation can be possible if cost effective options can be found.. Recently, a government enforcement for ban on transplantation of paddy before 15^{th} June is being gradually accepted and implemented by the farmers. However many attempts for agriculture diversification have remained unsuccessful. There was interest in the feasibility of using tanks for artificial recharge. Farmers were interested in the controlling the number of boreholes; they felt the political decision making waslacked long term vision.. Farmers felt the water user associations were weak and should be strengthened.

227. Farmers were supportive of crop diversification and but wanted technical support; farmers felt paddy was not sustainable. Farmers would like the minimum support price to be extended to other crops. Farmers were not satisfied with the subsidy system; they reported that the free power was factored into the MSP so in fact they were actually paying for the power. The present system of flat rate on the motor size was unsatisfactory and there was corruption in the collection. Farmers were interested in capacity building including training and support for awareness programs so they could better understand the issues. .

228. Understanding of climate impacts: !00% of farmers questioned felt there was climate impacts; cold weather is getting shorter, the cold period was previously 4-5 months will reduce to 1-2 months with adverse effect on the winter wheat with 25% loss of yield. All those questioned felt there was a reduction in rainfall with more erratic rainfall patterns. The occurrence of unseasonal rainfall especially showers during the harvest in November is affecting the yield at maturity.

229. Other impact reported include occurrence of hail stones used to be in March but now occur in November December in 2010 and caused major damage to crops (~ 25% -40% loss). Farmers noted the delay in the start of the monsoon which appeared to be delaying by 15-20days.

C. Surface and Ground Water Conjunctive Balance

230. Understanding the surface and groundwater balance is critical, although there is high losses in the surface water system the combined surface and groundwater system is actually quite efficient. Understanding this water balance is critical and modelling of the conjunctive water use is considered essential to support the decision making process. By using a water balance model different cropping and irrigation scenarios can be analysed; scenarios could include the impacts of the water balance; to changes to cropping, lining options, impacts of a change to drip or sprinkler system. Without fully understanding the complex water balance it is not considered prudent to embark on any major water management initiatives.

D. Agriculture

231. Food and nutritional security is a national priority. The Indo-Gangetic plains and particularly Punjab has traditionally been responsible for the food security of India. Therefore the market demand for wheat and rice cereals will always be increasing with growing national demand and with export markets.

232. Rice-wheat pattern is the provides the best combination to sustain farms incomes. The risk involved are negligible as the 'minimum support price' (MSP) fixed by the government covers any risk. Such MSP are not available for other cereals and oil seeds. There is unmatched stability of rice and wheat yield which is not available with other produce like vegetables, sugar cane etc.

233. Punjab farms are commercialized modern farms for obtaining maximization of profits. Various farm equipment and machines are in used which have been privately possessed by the farmers. Similarly labour specialization, procurement of various inputs like fertilizer, pesticides, nutrients etc have become set routines in the mind of farmers. Labour shortages are issues, wheat and rice offer opportunities for almost complete mechanisation. Paddy rice is largely mechanised except transplanting; to meet this need the government's is presently planning to introduce mechanised paddy transplanting cultivation with the agriculture department of the state engaging seven companies to arrange 700 paddy transplanters

234. Farmers are concerned about the heavy risk in diversification due to non availability of assured markets. For example sugar cane farmers are required to carry their production to the sugar miles and wait in queues for long periods at the door of sugar mill for delivery of their produce.. The payments are also not made immediately and it takes months or even year to get payments. Cost variation of vegetable and fruits produce are high and risk involved are big because proper markets for different variety of produce are not there.

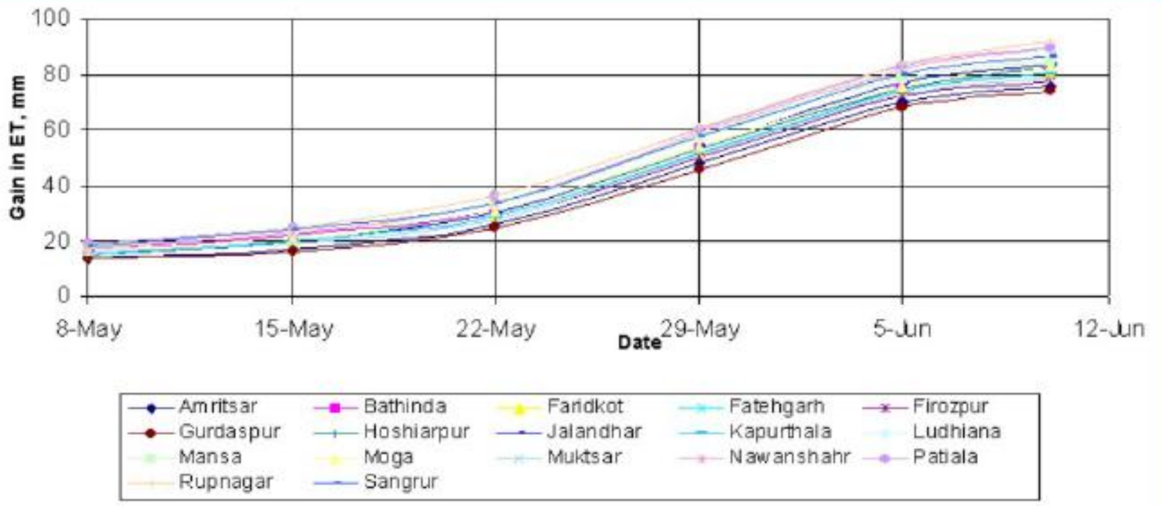
235. Due to above mentioned reasons shifting of rice wheat cultivation have not found favour with government and from farm community. Even government notifying some areas in the state for non-paddy cultivation may not workable solution due to political reason as paddy-wheat cultivation has also become prestige and competition issue with most of the farmers. This is in spite of the fact that present agriculture system is becoming unsustainable and non-profitable due to increasing cost and diminishing yields.. As per 'State of Environment Punjab -2007' report by Punjab Council for Science and Technology and MOFF Govt of India, the state's agriculture has reached at the highest production level possible under the available technologies and natural resources base and its growth has stagnated. High cost of production and diminishing economic return in farming are adversely affecting the socio-economic conditions farmers in Punjab.

236. Although potential yield of the rice and wheat is estimated to be about 10.7 t/ha and 7.9/ ha as in many other counties but the current actual yield is quite less. In the project report of canal lining submitted by Govt of India to Central Water Commission, the average yield of rice is estimated to be 4.2 tonne per hectare and that of wheat is 4.5 tonne per hectare in the Sirhind Canal System. During the discussion with farmers, they have indicated fatigue and decline in the crop yields. This is causing some weariness to the farmers who would not like their next generation to continue routine of farming and would like to diversify to other professions. Farmers reports impacts of warmer winters on wheat and other crops.

1. Agricultural Options to reduce Water Demand

237. **The Punjab Preservation of Sub Soil Act** which regulates sowing until May 10 and transplanting until June 10 is estimated by researchers to save 14 to 90mm or around 2180MCM if adopted over the whole of Punjab and would allow savings of 7% of the annual GW draft for the state[34]. These indicative savings can be are derived from the lower evapotranspiration and higher effective rainfall normally seen in June as shown in Figure 50. The big advantage for this strategy is the main gain is reduction of evapotranspiration with minimum effect on infiltration.

Figure 50 Evapotranspiration Gains by Delaying Planting



Evapotranspiration (ET) gains in the districts of Indian Punjab by delaying the transplanting date from May 1st to 10th June

238. **Reduction in the Area of Rice** appears to be generally supported by farmers if alternative cropping with equal returns can be found. Discussions with the Department of Agriculture indicate with the present crop prices and the MSP there is no viable large scale alternative presently available that

would meet the financial returns and security of the wheat rice. There were also some proposals for grant of subsidy of Rs 12,500 per ha to be given to the farmers who could shift to the crop system other than paddy or wheat. This proposal was not found to be practical because of its big financial implications to the state. In terms of consumptive use there is not such a large difference in crop demand. The main difference lies in the high requirement to pond and maintain the water in the field; most of which in fact would be infiltration, when considering the conjunctive efficiency would not be regarded as a water loss. Typical crop coefficients from FAO are shown in Table 35. How best reduction and diversification of rice can be best managed needs to be further studied. There are proposals to reduce a percentage of the rice area on a rotational basis.

[34] IWMI Research Brief Series V

Table 35 Typical Crop Coefficients

Crop	Kc initial	kc mid	kc-end
small vegetable	0.7	1.05	0.95
vegetables	0.6	1.15	0.8
roots tubers	0.5	1.1	0.95
legumes beans	0.4	1.15	0.55
chick pea		1	0.35
perennial vegetables	0.5	1	
Cotton		1.15-1.20	0.70-0.50
Spring Wheat		1.15	0.25-0.4
fodder	0.4	0.85-1.05	0.85
citrus	0.80	0.8	0.8
Sugar Cane	0.4	1.25	0.75
Rice	1.05	1.2	0.90-0.60

239. **Raised Beds**: Studies[35] in past decade indicates that sustainability of rice-wheat system in the Indo Gangetic Plains has been at risk mainly due to declining in groundwater levels, soil organic matter content and nutrient availability, increased soil salinization, incidence of pests and diseases. Practices commonly associated with sustainable management include accelerated adoption of resource conserving technologies (RCTs) and diversified crop rotations that enhance soil cover and fertility. In recent past a number of RCTs, like zero-tillage, bed planting, laser leveling, intercropping of high value crops in the systems, has been introduced in the rice-wheat cropping system in IGP. The adoption of furrow irrigated raised bed (FIRB) planting technique at the farmer's fields is at initial stage in the region. Experimental results indicated that FIRB technique is not only save the resources like water and nutrients and labour but also facilitates the greater diversification of the rice-wheat cropping systems. The level of potential and uptake in Punjab is not determined however Diversification of crops and cropping systems that have high water productivity, profitability and long-term sustainability with the availability of modern management techniques may prove a better alternative in this respect. FIRB planting offers the opportunities for prosperity with diversity. How well such techniques are adopted depends on the financial viabilities and the applicability to mechanisation.

240. **System of Rice Intensification**: The Department of agriculture has tried to introduce System of Rice Intensification SRI rice which can reduce the water demand however the findings are that the higher labour requirements were a serious issue and the farmers were not convinced of the water saving benefits, which had no financial benefit.

241. **Zero tillage** is now becoming more adopted -by utilisation of the residual soil moisture after the rice crop quite significant savings are possible.

242. **Consolidation into larger farming units** could lead to improved water use efficiency as well as efficiencies of scale, improved mechanisation. This may happen naturally as some of the younger generation farmers leave the land; although evidence shows that leavers rarely sell their land. Smaller farmers could farm in collective units which would allow savings in cultivation costs and improved facilities to market.

E. Surface Water Irrigation Management

243. Surface water irrigation is estimated to be providing about 25 to 30% of the water demand. Ongoing initiatives to conserve water are to provide lining to the main, distributory canals and water courses. In assessing the benefits of this work it is necessary to divide the irrigation area into two parts -north east freshwater aquifer and south west saline aquifer. The benefits in north east part must be assessed in terms of the conjunctive efficiency of the surface and groundwater systems. Benefits of lining are an increase in surface water efficiencies[36]; the bulk of these savings is reduction in infiltration which represents a loss of recharge; the gain in conjunctive efficiency is significantly less. The State Government is limiting lining to side lining in some main canals to ensure some continuation of the recharge. It is considered that the present practice of considering surface water efficiencies in isolation is inappropriate. For the parts in the fresh water aquifers it is essential to address 'conjunctive efficiencies' rather than the present practice of surface water efficiencies. Investments in lining will be

[35] Furrow Irrigated Raised Bed (FIRB) Planting Technique for Diversification of Rice-Wheat System in Indo-Gangetic Plains M.L. Jat et al**,**

[36] Estimates from IWMI and the NWM are surface water efficiencies of 50% unlined main canals, 70% for lined main canals and 60% for unlined water courses and 70% for lined water courses.

more cost effective in the parts of the system with a 'saline aquifer' where surface water efficiency parameters are valid..

244. Water allocations under the Warabandi system are supply led and do not address crop water requirements. The allocation is based on the land holding areas. With the very low surface water duties the spreading of scarce water over a large areas is inefficient and results in high losses-evaporative and infiltration. Field outlets from the irrigation system typically have a capacity at the turnout (locally termed mogha) of 3.5 cusecs per 1,000 acres, which is equivalent to 0.245 l/s/ha or 2.1 mm/day. The allocated time for allocation is only 10minutes per acre. After the completion of the allocated time the water is moved to the next field. With such low duties this spreading of water allows equitability at some cost to efficiency. The allocation time per unit area is the same for all plots; there is no allowance for losses within the water courses.

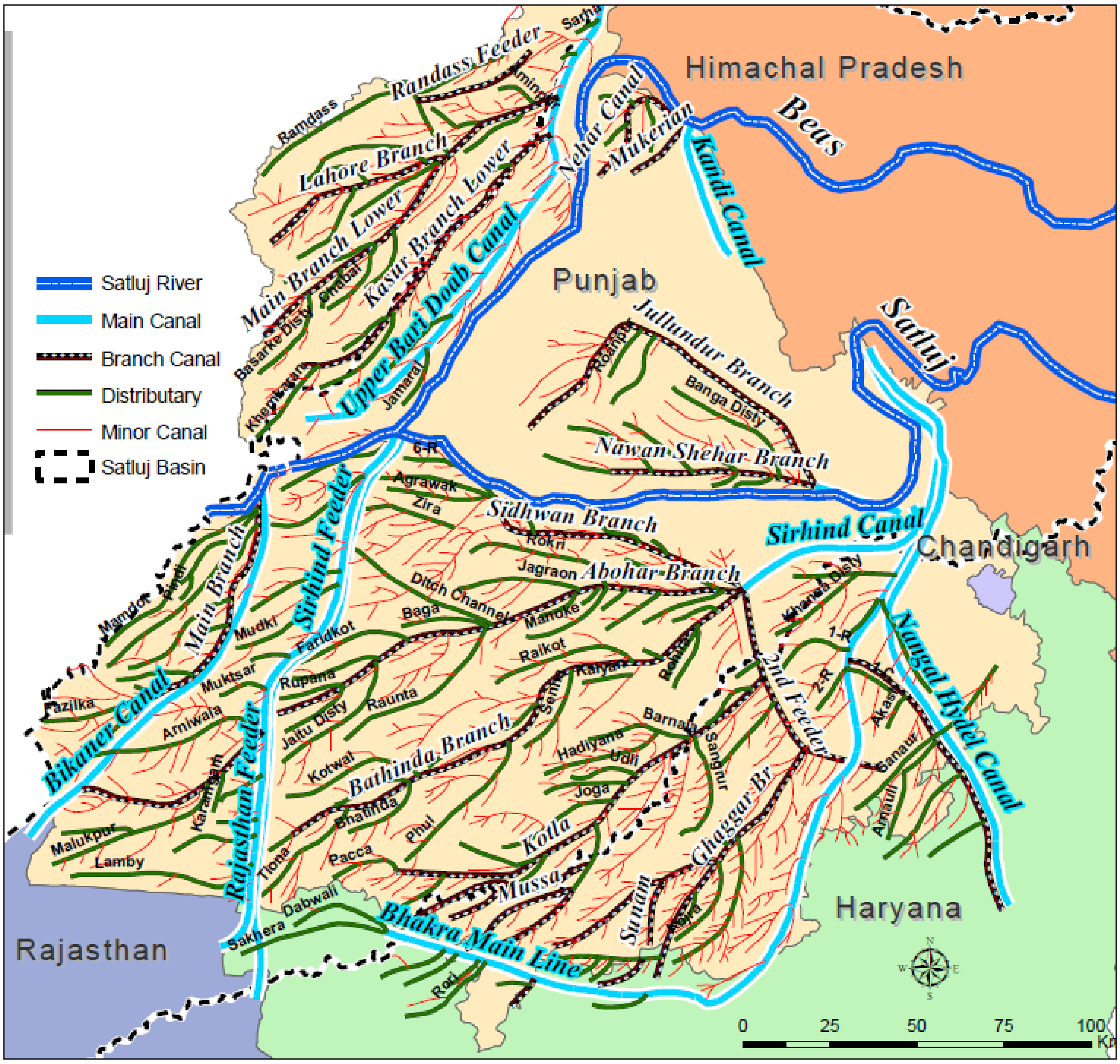
245. The outlets are controlled by steel insert flumes into the outlet structure-the actual allocations are very sensitive to the water level in the canal being set to the design water level. Low flows or poorly maintained sections or some manipulation the actual allocations can differ quite significantly from the design duties. Controlling the water level in the canal is critical and provision of water level gauges and some additional cross regulators may offer some facility to improve the accuracy of allocation though the turnout. There is no provision to close the outlet. There would appear to be potentials to improve the functioning of the turn out structures.

246. Allocations to branch canals are made according to a standard proportion of the supply. Flow measurement and allocation is by measuring the upstream and downstream water levels and the gate opening. The flow is calculated from a standard table. Flow calibration has been carried out but is fairly infrequent. Silt and sediment downstream of the gates can seriously affect the accuracy of gate measurement. Accurate allocations to the branch canals can improve the overall scheme efficiencies. Use of crump or broad crested weirs or measuring flumes can significantly improve the accuracy of measurement and allocation. Flumes are more transparent as gauges can be seen and read by interested parties.

247. The stored water in Bhakra has significant annual variations of +/- 40%. The allocations to the Sirhind system show quite lower but significant annual variations; ranging from plus 12% to minus 18% of the mean. The allocations primarily depend on the inflows to the reservoir. There would appear to be potential to optimise the water allocations and cropping depending on the reservoir condition. Farmers interviewed expressed interest in weather forecasts. Water availability in the reservoir is known some months in advance of release; snow assessments carried out at the end of winter could also further support advance information. Farmers could be advised of likely water availability which could improve planning and efficiencies. Bhakra Beas Management board is presently undertaking real time forecasting for flood flows and releases and it would be potentially useful to apply a similar approach and development of a decision support system for dry season flow and irrigation and agricultural management. Linking the rice area to be planted with the predicted water availabilities in Bhakra may offer potentials to improve productivities and support conservation.

248. **Period of Supply**: the irrigation system is supplying water for the whole year for drinking water and some irrigation however to meet the demands on double cropping a supply of about 240 to 280 days might be sufficient. How the offseason supplies for potable water and other use could be met without the irrigation canals should be investigated. There is no mechanism to close turnouts if there is no demand. The water benefits of the using of short period crops would be significant. The Sirhind command area which forms the main water use of Sutlej water in Punjab is shown in Figure 51.

Figure 51 Sirhind Command Area



F. Potable Water

249. Potable and industrial water are issues. Water quality is the main concern with high levels of salt (TDS) reported in mainly in the south west. In the other parts water quality is deteriorating more due to the problems of pollution from industrial and agricultural activities. Water is supplied by a canals or groundwater. Canal schemes are more appropriate for the larger or communities closer to the canal lines. The Government is implementing Reverse Osmosis treatment for village communities in 327 villages of of Bathinda, Mansa, Faridkot, Ferozepur, Sangrur, Patiala and Tran Taran at a cost of Rs 34 crore. These projects are being implemented by public private partnerships with the Government of Punjab.

250. The World Bank is supporting the Government of Punjab to improve drinking water supplies including ground water schemes as well as rejuvenation of surface water schemes. There are proposals to rejuvenate 346 canal based schemes with the latest drinking water disinfection systems along with the necessary repair and replacement of the machinery.

251. To meet the critical needs of safe drinking water and emergency use there maybe some options to source the deep aquifers for clean water.

G. Water-logging and Salinity:

252. The south-western zone of the lower Sutlej sub-basin has persistent water logging and salinity issues. This area has very limited recharge except from nearby canal systems and shallow and often rising water table with associated problems of salinity and water-logging. Skakya and Singh (2010) report on trials of a number of technologies to address these issues in Faridkot and Muktsar of Punjab State, including:

i) The use of multiple well-point system to skim freshwater floating above saline groundwater. The multiple well-points distribute the drawdown across the application area thereby reducing the upcoming effect. They recommend abstraction rates should not exceed 3 litres per second.
ii) Conjunctive use of canal water and poor quality groundwater. Trials in Faridkot resulted in improved yields for wheat and paddy. Soils in this area suffered from high sodium so gypsum was also applied to reduce alkalinity and improve soil permeability. The conjunctive use of canal water and poor quality groundwater had the added effect of lowering the water table and reducing the waterlogged areas.
iii) Biodrainage to lower groundwater levels through planting of highly transpiring Eucalyptus species. Although Shakya and Singh (2010) report on effective plantation methodologies rather than how effective the trees were in lowering the water table. – they recommend a ridge planting methodology. In Haryana Ram et al. (2007)[37] monitored groundwater levels in near a 18 year old Mysure gum plantation and reported that groundwater levels beneath the trees were almost 1m lower than in surrounding fields with a zone of influence of up to 730m from the trees. They recommend parallel strip plantations (66 m apart and two rows of plants in each strip) by the use of ridge planting techniques.
iv) Shakya and Singh (2010) also report in the use of Sub-Surface Drainage System (SSDS) in Muktsar where a drain network was installed at 1.75 m drain depth, maintaining water table at 1.2 m below the ground surface. They maintain that this was an economically viable solution for the farmers, in which salts are manageable and crop yield improved.

253. Each of these approaches would need to be evaluated for their appropriateness for each hydrogeological setting. A public participatory approach with relevant stakeholders and farmers' organizations would be essential to help evaluate these options. Many of these activities would be appropriate for community action. Financial packages to plant trees rather than crops might be considered.

H. Groundwater Irrigation Management

1. Introduction

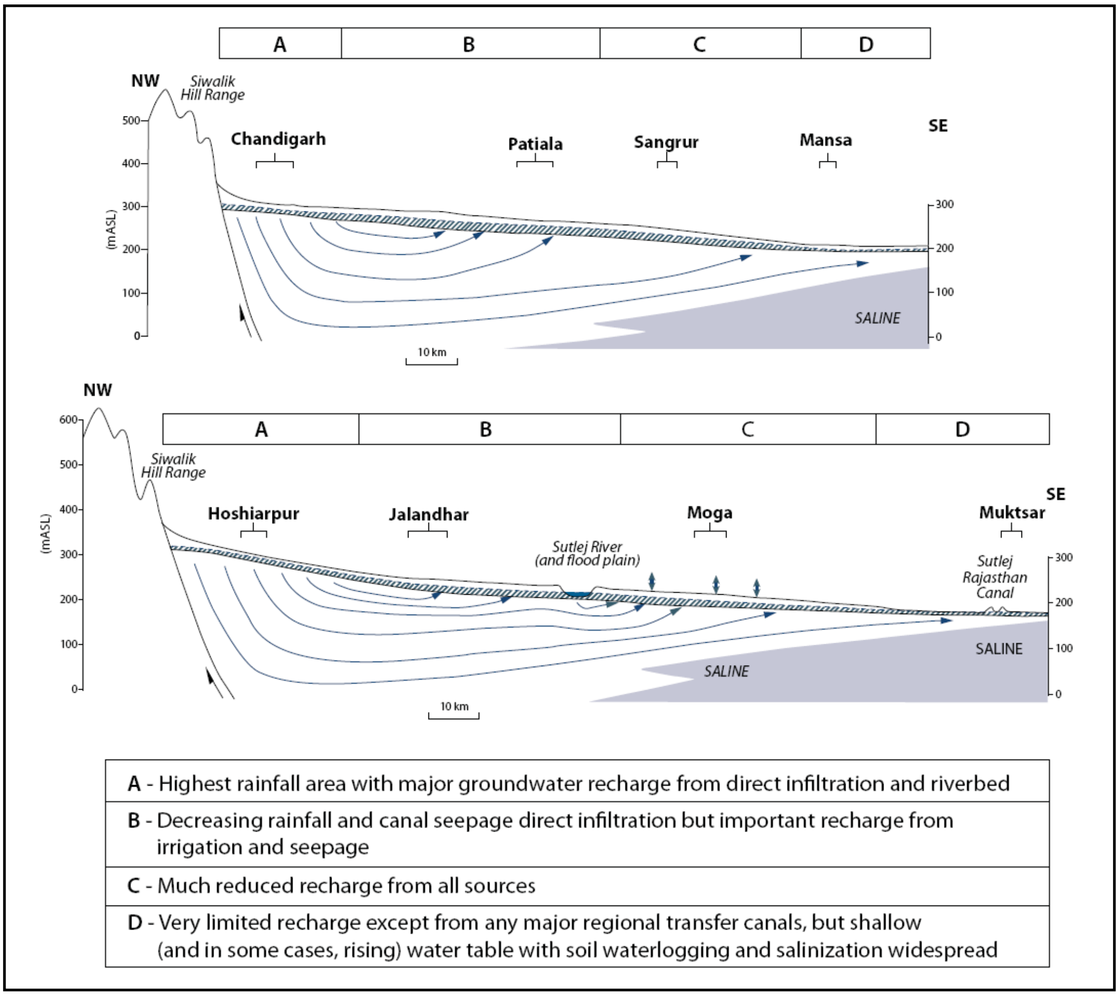
254. Groundwater is a key element for the integrated water resources management of Punjab state. Approximately 95% of agricultural land in Punjab is irrigated of which 30% is dependent on surface water from canal and the remaining 70% is supplied by groundwater from tube wells.

255. Groundwater management involves the below ground physical aspects of the aquifers abstractions, recharge together with the complex above ground system of socio economic and institutional factors Declining water table in Punjab due to heavy irrigation withdrawal far in excess of recharge has become biggest problem for Punjab agriculture. The ground water is also a major source of drinking water. Punjab was at the centre stage during the green revolution era of seventies and eighties. Over intensification of agriculture over the years has led to water depletion, reduced soil fertility and micronutrient deficiency. In addition to this, ground water pollution, resulting from injudicious use of farm chemicals has resulted in overall degradation water resources. Even the availability of safe drinking water is under serious threat. Increasing climate variability is now posing new threats to the sustainability of agriculture. Energy in the form of electricity plays a key role in performance of agriculture in Punjab as it is used extensively in pumping ground water for irrigation

[37] Ram et al. (2007) Biodrainage potential of Eucalyptus tereticornis for reclamation of shallow water table areas in north-west IndiaAgroforest Syst (2007) 69:147–165

and other farm operations. Free power to agriculture is also considered to be major reason for decline in the water table. The cross section of the Indus Alluvial plane in Punjab is shown in Figure 52.

Figure 52 Cross Section of the Indus Alluvial Plain



2. Supply Side Management

256. Artificial recharge (AR) systems are engineered systems where surface water is put on or in the ground for infiltration and subsequent movement to aquifers to augment groundwater resources. AR requires permeable surface soils to infiltrate to the aquifers. Where this is not available trenches or shafts in the unsaturated zone can be used. To design a system for artificial recharge of groundwater, infiltration rates of the soil must be determined and the unsaturated zone between land surface and the aquifer must be checked for adequate permeability and absence of polluted areas. The aquifer should be sufficiently transmissive to avoid excessive build up of groundwater mounds. Knowledge of these conditions requires field investigations and, if no fatal flaws are detected, test basins to predict system performance (Bouwer, 2002)[38].

257. The Groundwater Recharge Master Plan follows two criteria for identifying recharge: availability of surplus water and availability of storage space in aquifers. The investments in the program would therefore be driven by the potential available for groundwater recharge, and not by the need for recharge. Therefore there are some concerns nationally about whether the implementation of this plan will benefit the most water stressed areas. Indications are also that AR may not be suited to all hydrogeologically situations and may prove quite costly. Therefore, AR will be part of the overall

[38] Bouwer, H. (2002) Artificial recharge of groundwater: hydrogeology and engineering. Hydrogeology Journal, 10:121-142.

solution in certain circumstances but should not be seen as the panacea for over-exploitation or a justification for not tackling the demand related issues.

258. It is estimated that an area of 448 760 km2 — about 14% of total land area of India — is suitable for MAR and that a volume of 36 453 MCM is available for recharge annually. This is equivalent to an average of 80 mm over the entire area and the volume equates to about 18% of the 200 000 MCM of groundwater that is currently utilised annually for irrigation. However, the estimates of recharge sites in a DFID/BGS study (2006)[39] (that are not limited by storage in the aquifer), were found to be about one order of magnitude lower (4 mm to 10 mm) than the CGWB estimates and to represent only about 1% of rainfall.

259. The CGWB Master Plan for ground water recharge has identified an area of 16450 sq km as feasible for recharging ground water in the Sutlej sub-basin which could potentially yield an additional storage of 12,700 MCM. Given a total sub-basin area in the Punjab state of 50362 sq km, this equates to some 33% of the whole basin. It is estimated, by averaging thickness of the unsaturated zone that could be recharged to a depth of 3 m below ground level, that some 18864 MCM could be stored in the aquifers by artificial recharge. The principal recharge structures planned are vertical and lateral shaft with injection wells filled with inverted filter. It is estimated that this will require an estimated 294MCM of non-committed surface water per annum could be used to recharge the Sutlej basin. This equates to a depth of recharge of approximately 18mm across the 16450 sq km [(0.294 cubic kilometers/16450 sq km)*1,000,000 = 18mm). It is estimated that these artificial recharge structures have an average recharge efficiency of 75%, so the actual artificial recharge created by the planned structures would yield approximately 13mm across the artificial recharge area. This annual artificial recharge must be put against aquifer depletion rates of 0.7-1.2 meters per year, equivalent to approx. 100-200 mm per year of excessive abstraction (World Bank, 2010). Therefore, the cost and benefits accrued through this artificial recharge approach will need to be weighed against groundwater resource savings that could be achieved through other means such as the demand related savings outlined above.

260. The study considers that Artificial Recharge as an important requirement, however viabilities and cost effectiveness must be determined. With the preliminary information available it the potential role of AR is however not considered to be so significant and would only compensate a small fraction of the groundwater deficit.

3. Options for Geochemical Hazards:

261. Groundwater quality issues in the Sutlej basin include selenium in the Nawanshahar district, chromium and nickel in Ludhiana district and fluoride in Amritsar, Faridkot, Ferozpur, Bhatinda, Mansa, Muktsar and Sangrur districts. Problems with arsenic have also been reported in groundwater in southwestern part of the basin. Presence of heavy metals in groundwater is reported in the districts of Ludhiana and Fategarh Saheb.

262. An overall strategy in short and long term horizons to tackle the issue of naturally occurring trace elements in the groundwater[40] is presented in Table 36. Anthropogenic derived contaminants such as nitrate and heavy metals should be targeted to reduce or eliminate their production at source.

Table 36 Key Issues for Mitigation of Naturally Occurring Trace Elements

ACTION	ISSUES TO BE RESOLVED
SHORT TERM	
Evaluation of Problem	• appropriate scale (local/provincial/national) for groundwater quality survey • selection of appropriate analytical technique(s) (field kit/lab method) • government initiative versus private responsibility • availability of specialist advice for hydrogeochemical interpretation

[39] Calow, R C , Neumann , I, Moench, M, Kulkarni , H, Mudrakartha, S and Palanis ami , K. (2006) Managed Aquifer Recharge: an assessment of its role and effectiveness in watershed management. British Geological Survey Commissioned Report, CR/06/107N. 80pp.

[40] Foster et al. (2006b) Natural Groundwater Quality Hazards avoiding problems and formulating mitigation strategies. GW-MATE Briefing Note Series Note 14, World Bank.

ACTION	ISSUES TO BE RESOLVED
	• assessment of other potential groundwater quality problems
Water Supply Management	• advice on well use (community information/well closure or labelling) • practical and social considerations on well switching • prioritization of field analytical screening (to confirm safe wells) • appropriate screening policy (universal or selective/temporal frequency)
Public Health Programme	• patient identification (active program or via medical consultation) • establishing relationship between health problem and water source(s) • diagnosing incipient symptoms • immediate patient treatment (organization of bottled water provision)
LONG TERM	
Water Treatment Option	• cost at scale of application (town/village/household) and effectiveness/sustainability at scale of operation
Alternative Groundwater Supply	• usually involving (a) water wells with modified (often deeper) intakes or (b) reticulation from local high-yielding, acceptable quality sources, both of which must be based upon systematic hydrogeological investigation and implemented with appropriate well construction standards
Alternative Surface	• sustainability in terms of drought reliability and quality variability
Water Supply	• evaluation of risks associated with treatment plant failure

4. Demand Side Management.

263. **Regulation;** Punjab in general is generally not in favour of ground water regulation as it is felt that such a regulation will create a hardship to its farmers. Ground water regulations suggested by CGWB and other reform measures have also been rejected. Charging for power has very long been discussed issue but Punjab government has never accepted the proposal

264. There is preference to minimise over extraction by promotion of large scale artificial recharge. However recent regulation under the Punjab Subsoil Regulation Act to make mandatory that rice planting is delayed until June is gradually being adopted without any significant loss of production or higher cost to farmers. Punjab has in 2010 banned the sinking of tubewells in 300 villages. The state has however not accepted proposals to meter power supplies and increase the power tariffs as a means to reduce groundwater abstraction.

265. With a reported 2.3 million tubewells in the state it is extremely difficult for Government to control and regulate such a massive number of units. The political and social sensitivity of the issues make it difficult to contemplate major regulative initiatives would work without major provision of compensations. The subsoil regulation act demonstrates that farmers will respond and respect some element of regulation if they understand the logic and there is no or limited financial loss and a critical mass of farmers can be convinced to adopt the controls.

5. Electrical Power Management

266. Electrical Power Management**;** offers an indirect method to try and control the abstraction of groundwater. The present flat fee for power is Rs 50/hp/season; however recently requirements for payment have been suspended. In Gujarat the similar opposition to imposing tariffs and metering were opposed but a modified scheme has shown some reasonable success as described in Table 37 below.

267. **Power Impacts on Irrigation efficiencies**: groundwater irrigation efficiencies are higher than surface water due to the proximity of tubewells to the site as well as some use of pipes. Intermittent and unscheduled power is an issue which results in farmers pumping whenever power is available irrespective of crop need. Present cropping of rice largely preclude the more efficient methods of sprinkler and drip although there is some uptake of sprinkler and drip systems in some areas. It is important to consider conjunctive efficiency (integrated surface and groundwater). For example sprinkler with 85% application efficiency is more efficient than the application efficiencies of furrow 80% or flood 65% -the gain in efficiency is largely the reduction in infiltration with minimal reduction in evaporative losses. Drip with 90% efficiency linked to high intensity cash crops is a more attractive option and lower head requirement than sprinkler. Very low sediment levels in the irrigation canals would be suitable for drip or sprinkler. Farmers and efficiencies could benefit for improved power and

power made available to meet crop needs; which would reduce the present pumping regime of maximum pumping when power is available.

Table 37 Jyotirgram Scheme

Jyotirgram Scheme (JGS) in Gujarat
An initial scheme to install meters was suspended and replaced by the JGS scheme to separate the domestic and agricultural power systems. No individual metering was installed by metering but distributers were metered to assess overall demand. Villages were supplied with 24hour power but agriculture 8 hours based on 8 hours at full voltage, 3 phase power and at a prearranged schedule. Started as a pilot scheme in eight districts but extended to the full state. The farmers agreed to accept de facto rationing because reliable power supply on an announced schedule is preferable even for a limited number of hours during most of the year, as long as demand during the peak irrigation time is also met. There are mixed reports on the scheme; some positive and some not so positive The rationing has affected the informal water markets lower income farmers who used to purchase water from larger farmers were hit due to the rationing. Other reports show more efficient use of power and groundwater in agriculture, due to the high reliability of power available on a preannounced schedule; 37 percent reduction in aggregate use of power in groundwater irrigation between 2001 and 2006, and a concomitant reduction in groundwater draft.

6. Community Managed Groundwater

268. There is an increasing interest in the role of communities to support regulation and control of groundwater. Community management is aimed at creating self governing groundwater user organisations that can be given the responsibility of sustainable management of aquifers through collective monitoring of aquifers and behaviour of groundwater users[41]. Projects in Andhra Pradesh through the farmer managed groundwater systems project are reported to have achieved some reasonable success. In Punjab the establishment of water user associations is very low, associations are very weak. Consultations with farmers especially the more progressive farmers indicate a need to develop on strengthen water user associations who might take more responsibility for management and reduce the dependence on the largely government managed warabandi.

269. The results of the participative rural appraisal carried out as a part of the studies indicated a high level of support for a portfolio of actions. Conjunctive use with changed cropping pattern and additional support price for non paddy and wheat crops were seen important. There was a general consensus that no single fragmented action would be useful.

I. Modelling Irrigation Water Use in the Sirhind Command

1. Introduction

270. Current groundwater use in the irrigated areas of Punjab is unsustainable. It has variously been estimated that surface water provides less than 30% of irrigation water supplies, with groundwater making up the remainder. It has also been variously estimated that groundwater use in many blocks in Punjab exceeds recharge by as much as 45%, resulting in continued and significant groundwater decline.

271. Cropping in Punjab is predominantly rice during the kharif season, followed by wheat during the Rabi season. Both of these crops have a minimum support price provided by Government, and are therefore very attractive crops for farmers, with little associated risk. In addition, farmers do not at present pay for electricity supplies and are therefore less mindful of the requirement for efficient groundwater use.

272. A number of measures are being considered through which the water resources system might be returned to a sustainable development condition. These include:

[41] Deep Wells and Prudence Towards Pragmatic Action for Addressing Groundwater Overexploitation in India World Bank

- switching to a rice variety that has a shorter growing season (120 days instead of 145 days);
- switching to direct seeded rice, which does not require initial puddling of fields;
- improving irrigation efficiencies;
- reducing the area cropped with rice, or rotation with a crop that has lower water requirements.

273. In order to improve understanding of the impacts that the above options might have, it was considered appropriate to set up a water balance modelling approach for an individual distributary canal within the Sihind irrigation command. The WEAP model was chosen for this for a number of reasons:

- it represents the physical system in a readily understood manner, and can do so to differing degrees of complexity, depending upon the level of information available;
- it provides for conjunctive surface water and groundwater use;
- it has a very user friendly interface and is easily set up;
- it has a well structured approach to scenario analysis and results presentation;
- it can incorporate economic functions;
- it's use could be extended to analysis of wider water allocation problems.

274. Licenses for the WEAP model were obtained by staff of CWC and NIH.

2. The Joga Distributary

275. The Joga distributary is located on the Kotla Branch of the Sirhind command, and includes parts of the Sangrur and Barnala districts. The location is shown in Figure 53 There are a total of 7 minor canals offtaking from the Joga distributary. Table 38 summarises the gross areas and culturable commands. The Joga distributary and minors are lined whilst the Kotla Branch canal is side lined.

276. Flow records for the Joga canal were obtained for the last three years to give an indication of surface water supplies to the command area.

277. Figure 54 presents 7-day surface water supplies for the last three years. There is clearly significant flexibility in the operation of the canal. It is not known to what extent the operation is driven by farmer demands and to what extent it is driven by flow availability in the system as a whole, and variability of demands across the system. What is clear is that strict rotation is not applied.

278. The discharge capacity at the head of the Joga distributary is 7.63 m^3/s. This gives a potential average delivery of 0.241 l/s/ha. Field outlets generally have a capacity of 3.5 cusecs per 1000 acres which is equivalent to 0.245 l/s/ha, and is close to the gross supply at the head of the distributary, and in fact to the potential supply to the Sirhind command. There are reportedly 140 outlets from the Joga system, resulting in an average area per outlet of 225 ha.

279. The average annual surface water delivery to the Joga distributary in the years 2008 to 2010 was 105 Mm^3, which is equivalent to a gross annual surface water irrigation delivery of 330 mm. This may be compared with a gross annual delivery at the head of the Sirhind command of 340 mm.

Table 38 Areas irrigated from the Joga Distributary

Distributary / Minor	**Gross Area (ha)**	**Culturable Command Area(ha)**
Joga Distributary	14,190	11,433
Dhurkot Minor	1,290	1,087
Minor No. 1	3,099	2,709
Mandi Minor	9,922	8,556
Sub-minor No. 1 of Mandi	2,299	2,139
Sub-minor No. 2 of Mandi	1,308	1,088
Sub-minor No. 3 of Mandi	1,053	882
Chowke sub-minor	1,567	1,358
Khokhar sub-minor	3,102	2,344
Total	**37,830**	**31,596**

Figure 53 Location of the Joga distributary

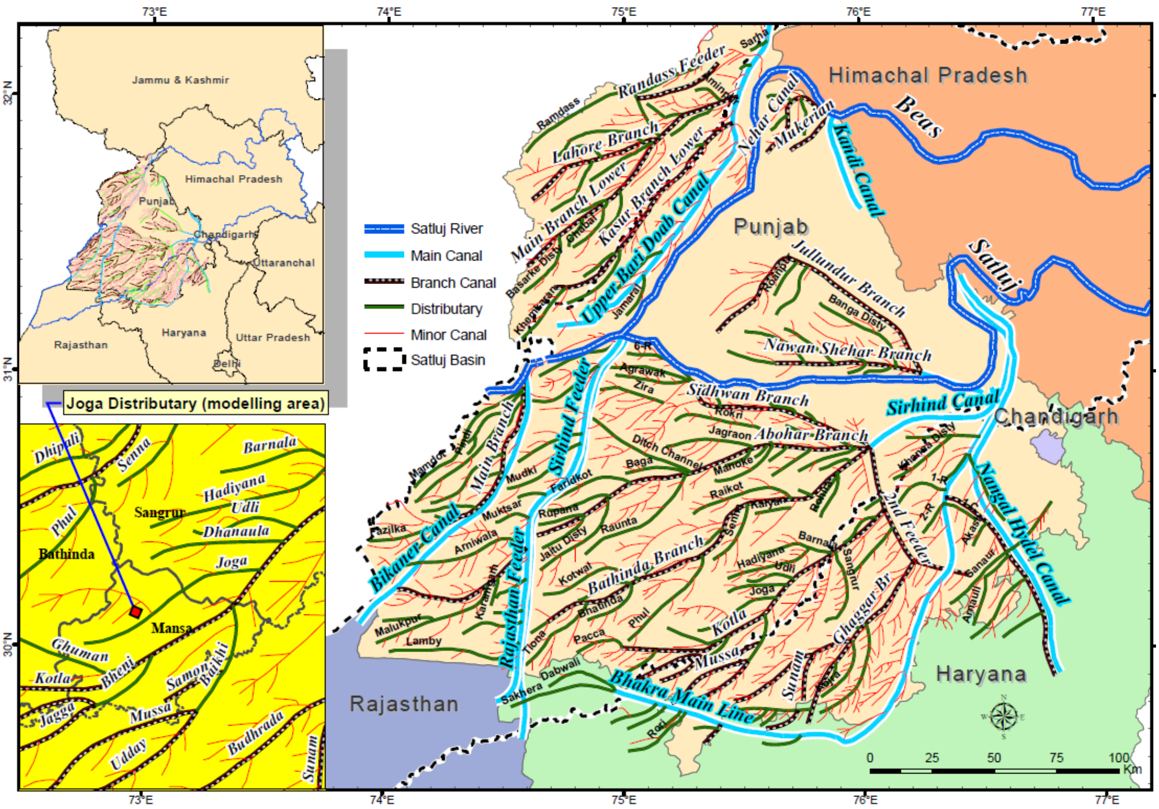
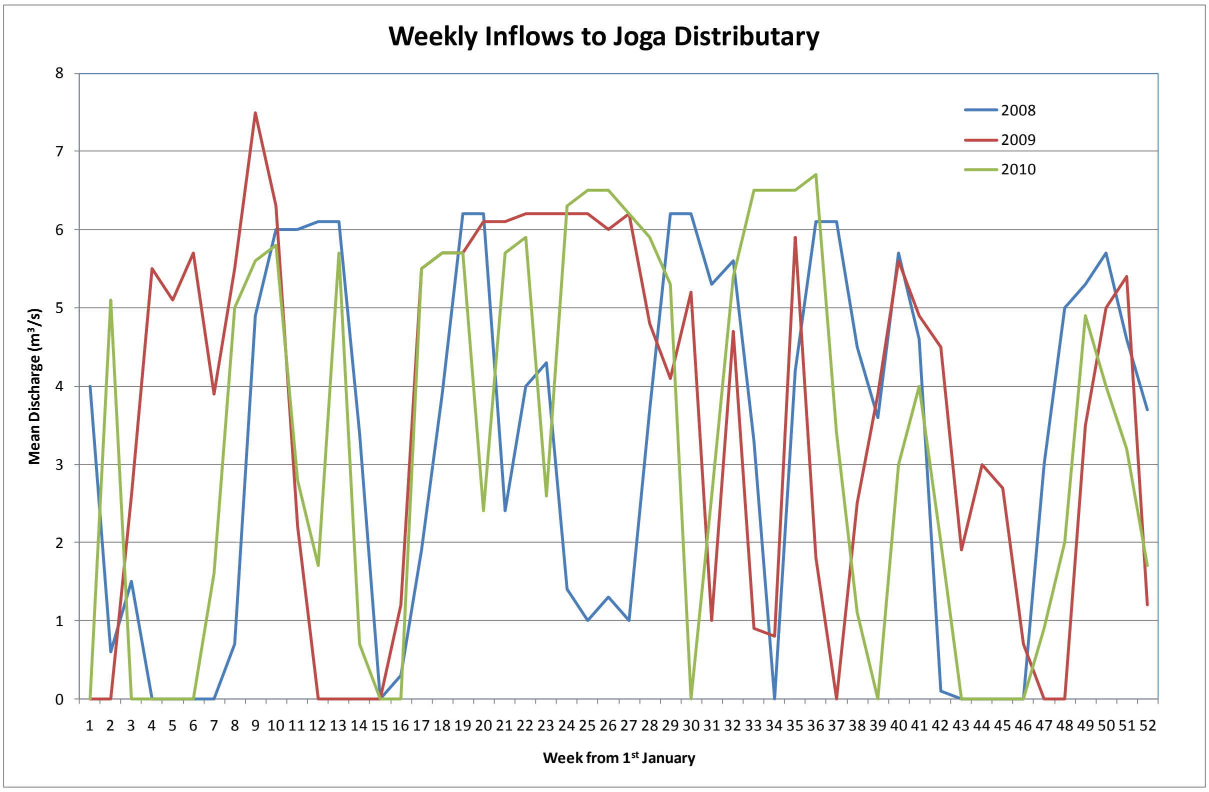


Figure 54 Mean weekly inflows to the Joga Distributary



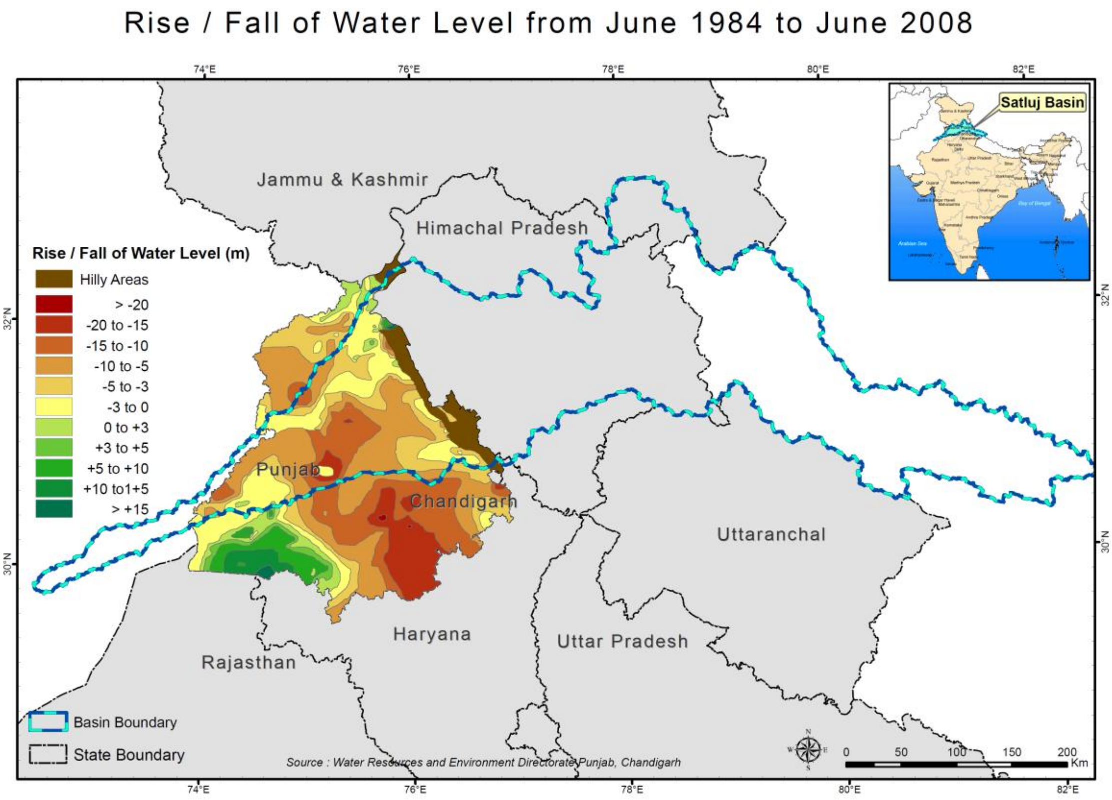
3. The Groundwater System

280. Data on groundwater use and resource potential in Sangrur and Barnala districts were provided by the Punjab Water Resources Department for the 2008-09 water year. Data on tubewell numbers were provided by the Agricultural Department. In 2008-09 the groundwater abstraction in Sangur district was estimated to be 3,700 Mm^3, and in Barnala was 1,238 Mm^3. Expressed in terms of a unit depth of water over each district, the abstraction in Sangrur was equivalent to 990 mm depth, and that in Barnala to 916 mm depth. In Sangrur approximately 96% of pumps are electric, and in Barnala approximately 95% of pumps are electric.

281. Groundwater resources are significantly over-exploited in both districts. The Punjab WRD estimate over-exploitation in Sangrur in 2008-09 by 2280 Mm^3 (equivalent depth of 610 mm), and in Barnala by 1238 Mm^3 (equivalent depth of 425 mm).

282. The depth to groundwater is typically of the order of 30 m in this area. Figure 55 shows the change in depth to water table depth between 1984 and 2008 estimated by the Punjab WRD. In the area of the Joga command the water table is estimated to have fallen by about 15 m in the period 1984 to 2008.

Figure 55 Rise/Fall of Water Level estimated by Punjab WRD

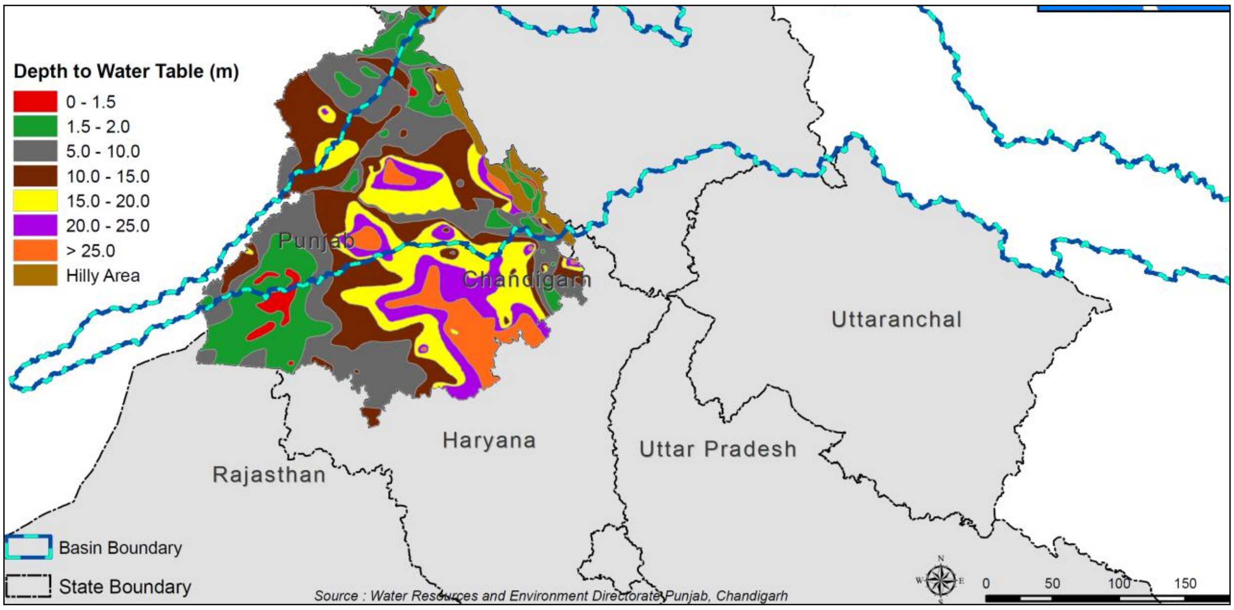


283. Figure 56 shows depth to water table for the Sirhind command for October 2008. There is a northeast to southwest groundwater gradient to the northwest of the Sangrur and Barnala districts, while to the west and southwest, the groundwater gradient is significantly reduced. The implication is therefore that there is lateral recharge to the Sangrur and Barnala districts from the northeast, and only minimal through-flow to the southwest.

284. Taking a transmissivity of 800 m^2/day, a boundary inflow length of 50 km, and an average gradient of 0.001, the flow into the Sangrur and Barnala districts would be of the order of 45 mm as an equivalent depth over the irrigated area of the Joga Distributary. Inspection of groundwater depth maps prepared by the Punjab Water Resources Department, and of isolines of piezometric surface for the years 2000 and 2010, indicates that the rate of groundwater decline in the last ten years has been of the order of 1 m/year. With a specific yield of 0.15, the equivalent groundwater overdraft expressed

as a depth of water would be 150 mm. This does not match well with the estimated overdraft for 2008-09.

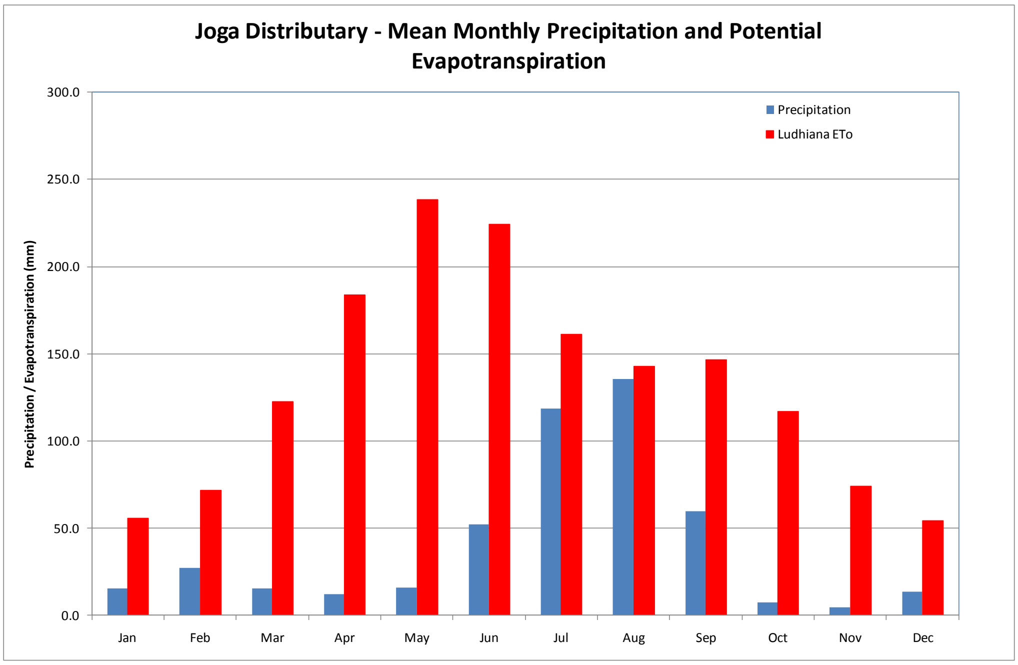
Figure 56 Depth to Groundwater October 2008



4. Precipitation and Potential Evapotranspiration

285. Historic precipitation data for the area was taken from the IMD gridded data set for the grid square centred on 75.5^{o} east, 30.5^{o} north. Potential evapotranspiration was calculated from data for the IMD climate station at Ludhiana, which was the closest to the area. Figure 57 presents the mean monthly precipitation and potential evapotranspiration for the Joga Distributary. There is a significant potential evapotranspiration deficit. Mean annual precipitation is 480 mm, and mean annual potential evapotranspiration is 1590 mm.

Figure 57 Mean monthly precipitation and potential evapotranspiration for the Joga Distributary



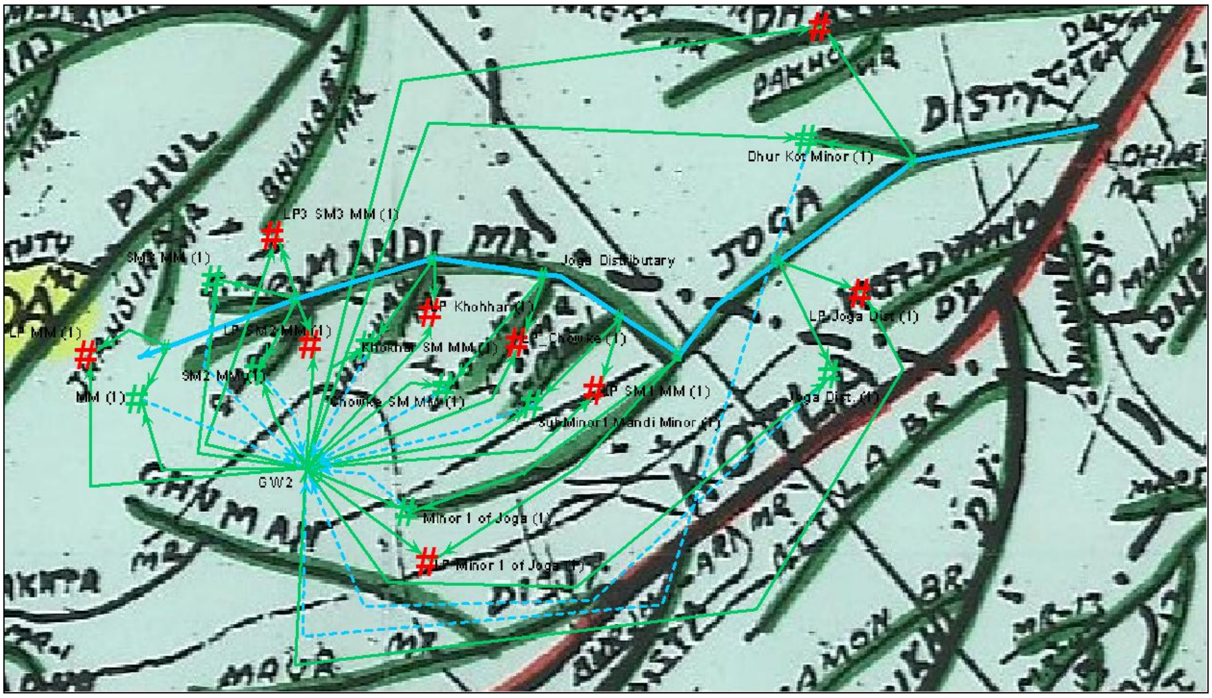
5. Representation of the System in WEAP

286. The schematic of the WEAP model of the Joga distributary is shown in Figure 58, super-imposed on a map of the canal system. The Joga canal is represented in blue, with minor canals going off to irrigation nodes or catchment areas represented in green, and land preparation nodes represented in red. Losses are permitted from the Joga canal by bed seepage. Losses in minor canals and field losses are expressed in terms of:

i) system losses, which may be considered as non-beneficial evaporation, leaving the system entirely;
ii) infiltration losses that recharge the groundwater system.

287. System losses have been set at 10% for all areas, and infiltration losses at 50% for paddy rice, and 30% for wheat. Each minor canal has a supply capacity constraint that is defined by the estimated canal capacity.

Figure 58 WEAP model schematic for the Joga Distributary



288. In each catchment area, the entire cultivable area is assumed to be cropped with rice during the kharif season, and with wheat during the rabi season. For non-cultivated areas, 30% of rainfall is assumed to contribute to groundwater recharge, while in cropped areas, 80% of rainfall is assumed to be effective in meeting crop water requirements.

289. A single groundwater storage is included in the model. The groundwater is represented as a tank, that is recharged from canal and field infiltration losses, and an element of rainfall recharge from fallow areas. Each catchment or irrigation area is connected to the groundwater storage with a transmission link. This has been left unconstrained. The model will first try to satisfy any irrigation demand from surface water, and will abstract groundwater to make up any shortfall in supplies. Irrigation demands are calculated internally in the model from supplied crop coefficients, potential evapotranspiration and effective rainfall. Weekly crop coefficients were estimated from the data presented in FAO Irrigation and Drainage Paper 56.

290. The model has been set up with a time series of historic potential evapotranspiration calculated from data for the IMD climate station at Ludhiana, and with precipitation from the IMD gridded rainfall data set. The data were established for the period 1977 to 2005. Historic canal flow data were only obtained for the period 2008-2010. It was assumed that these data are representative of historic conditions, and for modelling purposes a synthetic flow record was created in which these three years were simply repeated between 1977 and 2005.

291. Catchments or irrigation areas can either be modelled using a soil moisture accounting model, or using an FAO rainfall-runoff approach. The soil moisture accounting approach is the most sophisticated, but requires information on soil water holding capacity, as well as infiltration capacities. An advantage of the soil moisture approach is that it also permits ponding for paddy rice, while rainfall runoff model does not. However, within the time frame available for the studies presented here, sufficient data could not be obtained to permit application of this method. It was therefore necessary to incorporate additional demand nodes at each catchment or irrigation area, to represent water demands for land preparation and puddling for paddy rice. These are the red nodes in Figure 9. In setting land preparation demands, an allowance was made for the contribution of land preparation to crop water requirements. Typically land preparation requires about 250 mm depth of water. However, some of this will directly recharge the groundwater and some will be available to meet crop water requirements. There will be non-beneficial evaporation during the land preparation process and prior to transplanting. This has been assumed to be 50 mm, and this is what is input as the land preparation demand, rather than 250 mm. In future modelling it would be preferable to work with the soil moisture accounting approach.

292. The WEAP model is capable of enumerating basic economic and financial data. The value of crop production can be calculated, as can the cost of water supplies. The cost of farm inputs for both rice and wheat is reported to Rs10,000/ha. A breakdown of the budget is given in Table 39. The price that a farmer gets for rice and wheat is determined by the MSP which is Rs 10.3 / kg for rice, and Rs 11.2 / kg for wheat. WEAP can calculate crop yield in response to water stress, but in the application reported on here there is no water stress as groundwater abstraction is assumed to make up for any shortfall in surface water irrigation supply. The model has therefore been provided with the 2009-10 average yield figures for Punjab of 5985 kg/ha for paddy rice, 4010 kg/ha for non-paddy rice and 4400 kg/ha for wheat.

Table 39 Components of the crop budget

Item	**Cost (Rs)**	
	Rice	**Wheat**
Seed	500	500
Fertilizer / herbicide	1500	2500
Labour	2000	2000
Machinery		1000
Diesel for pumps		1000
Irrigation	5000	2000
Harvesting	1000	1000
Total	10000	10000

293. Costs for groundwater abstraction have been included in the model. Although at present farmers are not paying for electricity to drive their pumps, there is an economic cost to the state. The cost of groundwater abstraction is calculated on the basis of drawdown in groundwater storage, from an assumed initial level of 25 m below ground surface. Storage drawdown is converted to an average drawdown in groundwater level over the entire Joga command area, and the energy required to pump through this head calculated assuming a pump efficiency of 70%. WEAP permits the creation of scripts to calculate quantities that are not already included in the model.

6. WEAP Modelling Results

294. **Model outputs**: A wide variety of results output and presentation is possible from WEAP. The most useful outputs for the present study are time series of groundwater storage, water supply costs and the net value of agricultural production. The WEAP model was run for a 28 year time series. Scenarios considered were as follows:

i) Reference, in which current practices of cropping and groundwater abstraction continue;
ii) Short growing period variety of rice introduced (existing 145 days reduced to 120), permitting further delay of transplanting into July;
iii) Direct seeded rice introduced everywhere, dispensing with need for nursery and water application for puddling; planting early in July;

iv) Groundwater losses with direct seeded rice reduced from 50% to 30%; field losses with wheat remain at 30%;
v) Reduction in area planted with rice by 25%.

295. The above scenarios were considered to be incremental, in that scenario iv) was based on the assumption that scenario iii) had already been implemented and scenario v) was based on the assumption that scenario iv) was already implemented.

296. Figure 59 presents the time series of groundwater storage under each of the above scenarios. With the reference scenario, groundwater storage continues decline. The average annual groundwater overdraft, expressed in depth of water over the gross command area is 469 mm, a figure that agrees very well with the Punjab WRD estimate of overdraft in Sangrur in 2008-09. The indication is therefore that the model representation of the system is reasonable. The components of the mean annual water balance are summarised in Table 40 for the reference scenario.

Figure 59 WEAP simulated changes in groundwater storage under different crop scenarios

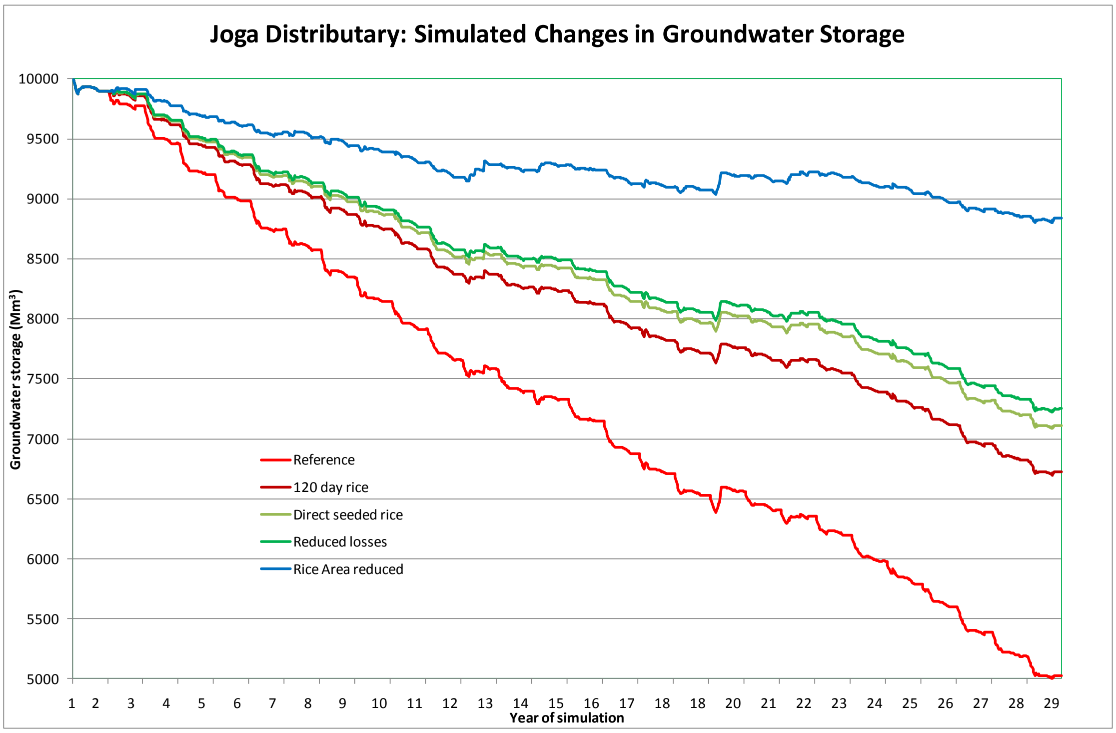


Table 40 Water balance components, Joga Distributary

Component	**Depth (mm)**
Annual Precipitation	478
Effective precipitation for crops	225
Gross surface water irrigation	330
Gross groundwater irrigation	1326
Net Irrigation	806
Irrigation + effective precipitation	1031
Potential evapotranspiration	1592
Actual evapotranspiration	1031
Unmet demand	0
Groundwater recharge	764
Groundwater overdraft	562
Groundwater overdraft over gross area	469

297.

298. Net irrigation plus effective precipitation balances actual evapotranspiration. The gross groundwater abstraction figure of 1326 mm is the equivalent abstraction expressed as a depth over

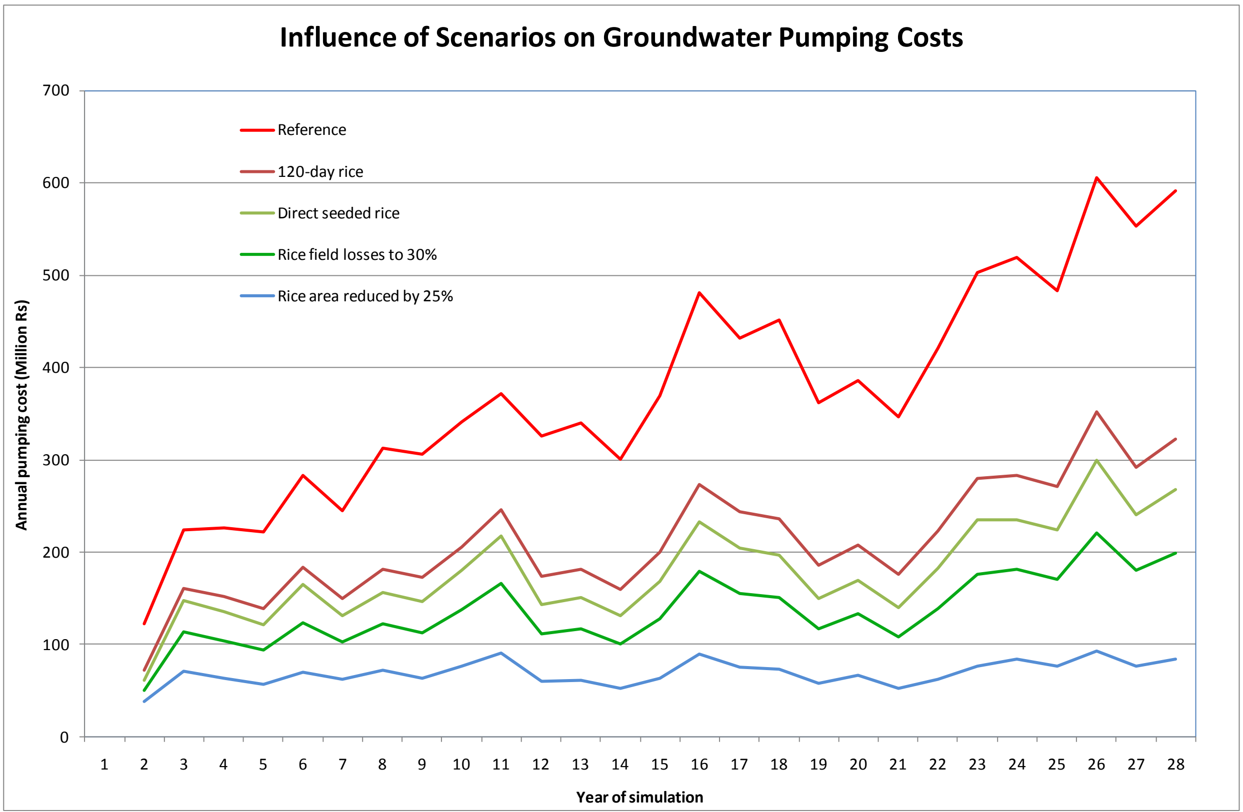
the irrigated area, and is equivalent to a depth over the gross area of 1108 mm, which compares reasonably well with the 990 mm gross abstraction estimated by Punjab WRD for 2008-09. The groundwater overdraft, expressed as a depth over the total command area is 469 mm, which again compares reasonably with the estimated overdraft by Punjab WRD for 2008-09 of 610 mm in Sangrur and 425 mm in Barnala. However, with a specific yield value of 15%, an overdraft of 469 mm would equate to an annual groundwater drawdown of 3.1 m. The observed groundwater decline over the past 10 years has been of the order of 1 m/year.

299. In the water balance presented in Table 40, account has not been taken of lateral groundwater inflow, that could be of the order of 50 mm/year, which would hardly explain the differences. An annual groundwater decline of 1m equates to a groundwater overdraft of only 150 mm. The discrepancy between the simulated overdraft and that observed is about 250 mm, taking account of lateral inflow. Possible reasons for this could be that potential evapotranspiration is being over estimated and effective precipitation under-estimated; that insufficient account is being taken of residual soil moisture contributing to wheat water requirements; that the actual cropping intensity is lower than that assumed, or a combination of these factors. It is of course possible that the overdraft report by Punjab WRD for 2008-09 was unrepresentative of the longer term conditions. Residual soil moisture following the rice crop could provide 100 - 150 mm for the wheat crop, although in terms of the WEAP model, this would currently be going to recharge.

300. Despite the above reservations about the accuracy of the simulated water balance components, the WEAP model can give useful insights into the effect of different strategies to arrest the existing groundwater decline. From Figure 10 it will be noted that introducing a rice variety with a shorter growing period results in a significant reduction in the rate of groundwater storage depletion. Introducing direct seeded rice improves the situation further, as water requirements for land preparation are significantly reduced, and there is no longer a need for nursery plots. Improving the efficiency of irrigation for rice by reducing infiltration losses only has a small impact on groundwater storage decline, although will be expected to have a larger impact on pumping costs. Reducing the area planted with rice by 25%, almost restores the system to sustainable groundwater use. It is clear that agricultural technologies will have a significant role in restoring sustainable water use.

301. **Pumping costs**: If action is not taken to arrest the groundwater decline, pumping costs will continue to increase. Under the reference scenario for a period of 28 years, the annual cost of pumping increases by 500 million Rupees, or by 18,700 Rs/ha. The economic return per irrigated ha would thus be reduced significantly. Figure 60 presents the annual pumping costs. Annual pumping costs are reduced significantly with the scenarios considered. The cost per hectare for groundwater irrigation with direct seeded rice and a reduced groundwater area would be about 2,670 Rs/ha.

Figure 60 WEAP Simulated Pumping Costs



302. **Crop returns**: In the scenarios considered, optimal yields would be achieved throughout. For a farmer growing a crop or rice followed by a crop of wheat, the net return would be 90,900 Rs/ha on the basis of crop budget data given in Table 39

303. **Potential climate change impacts**: An assessment of potential climate change impacts on the groundwater situation in the Joga distributary was made assuming that direct seeded rice had been introduced, that irrigation efficiencies were improved, and that the area of rice was reduced by 25% (i.e. scenario 5). The following additional scenarios were considered:

(i) Directed seeded rice, improved efficiency, rice area reduced by 25%, observed climate;
(ii) As above with PRECIS A1B baseline climate;
(iii) As above with PRECIS A1B mid-century climate;
(iv) As in v) but precipitation increased by 20%, no change in ETo;
(v) As in v) but precipitation reduced by 20%, no change in ETo.

304. Results are presented in terms of groundwater storage changes in Figure 61. No adjustments were made to the PRECIS A1B data. PRECIS A1B precipitation for the baseline period is some 30% higher than observed precipitation from the IMD grid. Figure 62 shows mean weekly observed precipitation plotted with mean weekly PRECIS precipitation. Clearly PRECIS significantly over-estimates precipitation in this area. Annual ETo simulated from PRECIS climate data is more closely matched with ETo calculated from observed climatic data at Ludhiana. Mean monthly ETo values are shown in Figure 63. The PRECIS A1B scenario indicates a 20% increase in precipitation by mid-century, and no significant change in potential evapotranspiration. Groundwater storage is sensitive to precipitation, with a 20% increase in precipitation bringing groundwater storage to a more sustainable condition. The PRECIS A1B baseline over-estimates precipitation, and hence with the mid-century projection there would be an apparent increase in groundwater storage with recharge exceeding extraction. This is considered to be an unlikely scenario. The scenario of direct seeded rice accompanied by improved efficiencies and a reduced rice area would not be adversely affected by climate change, and irrespective of what that change is, will improve conditions of groundwater storage.

Figure 61 Sensitivity of groundwater storage to climate

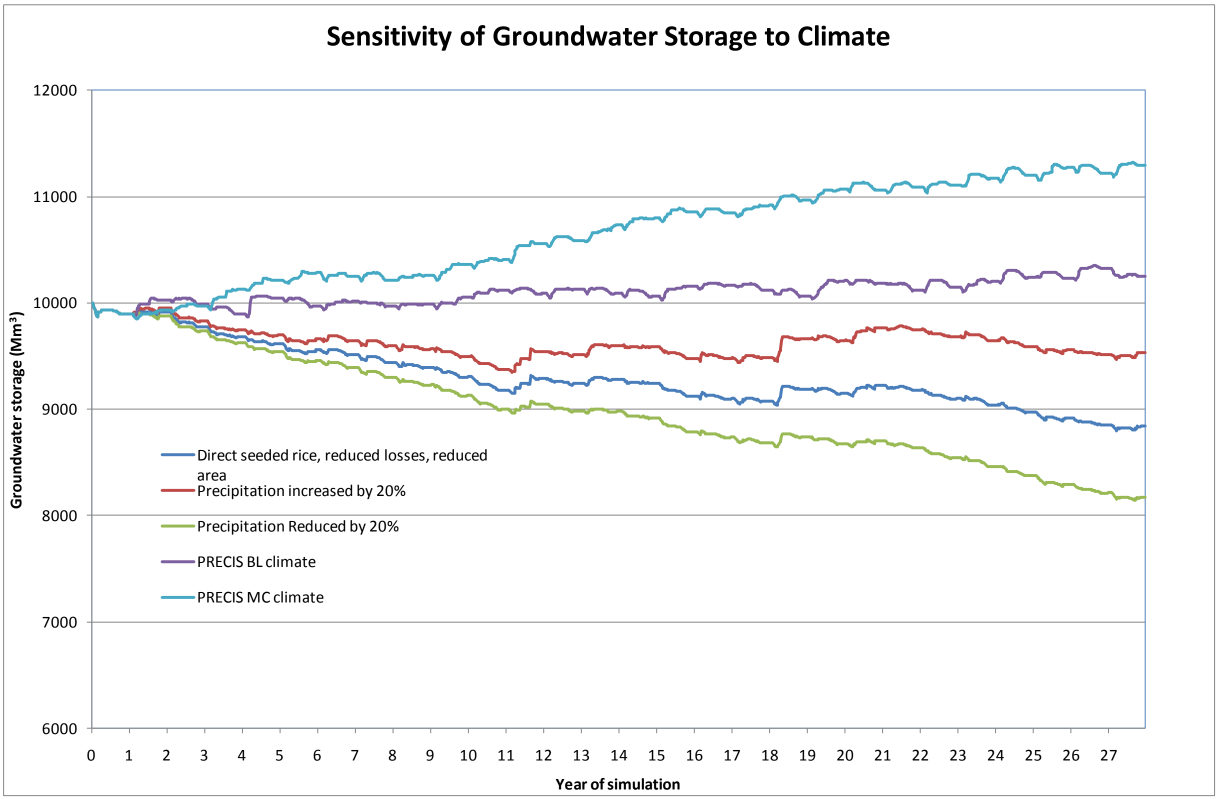


Figure 62 Mean Weekly Precipitation

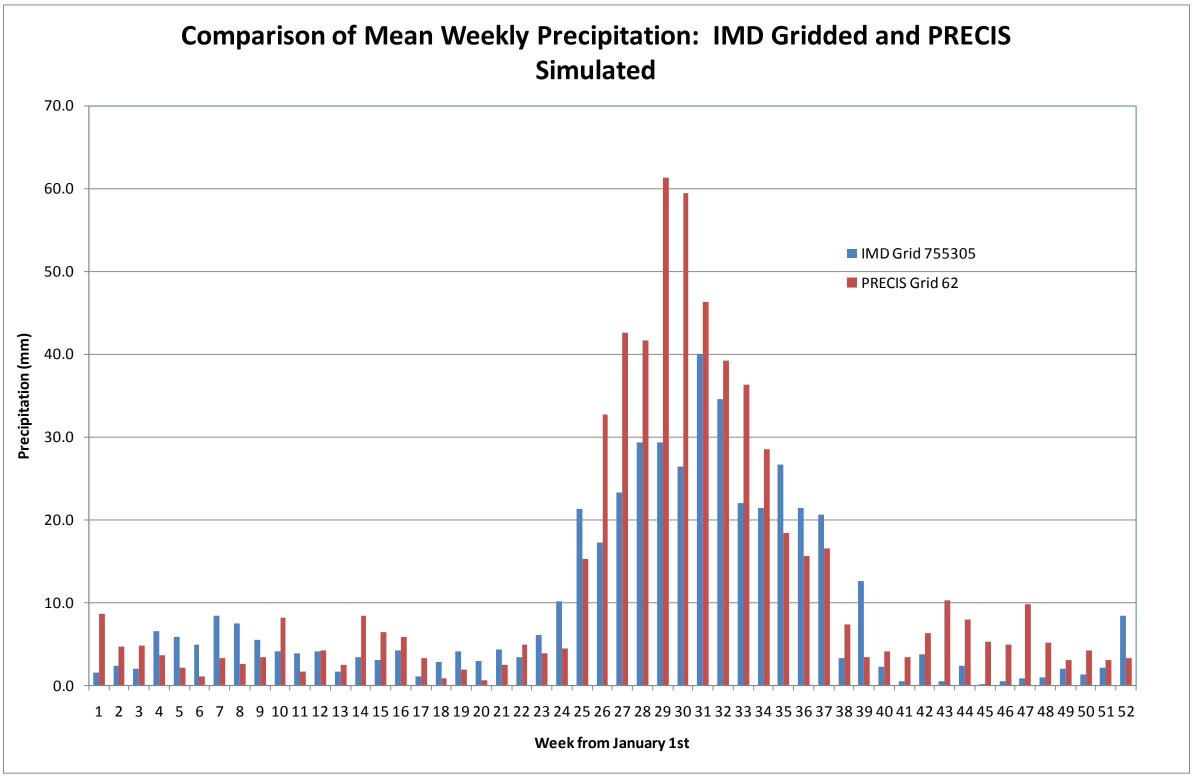
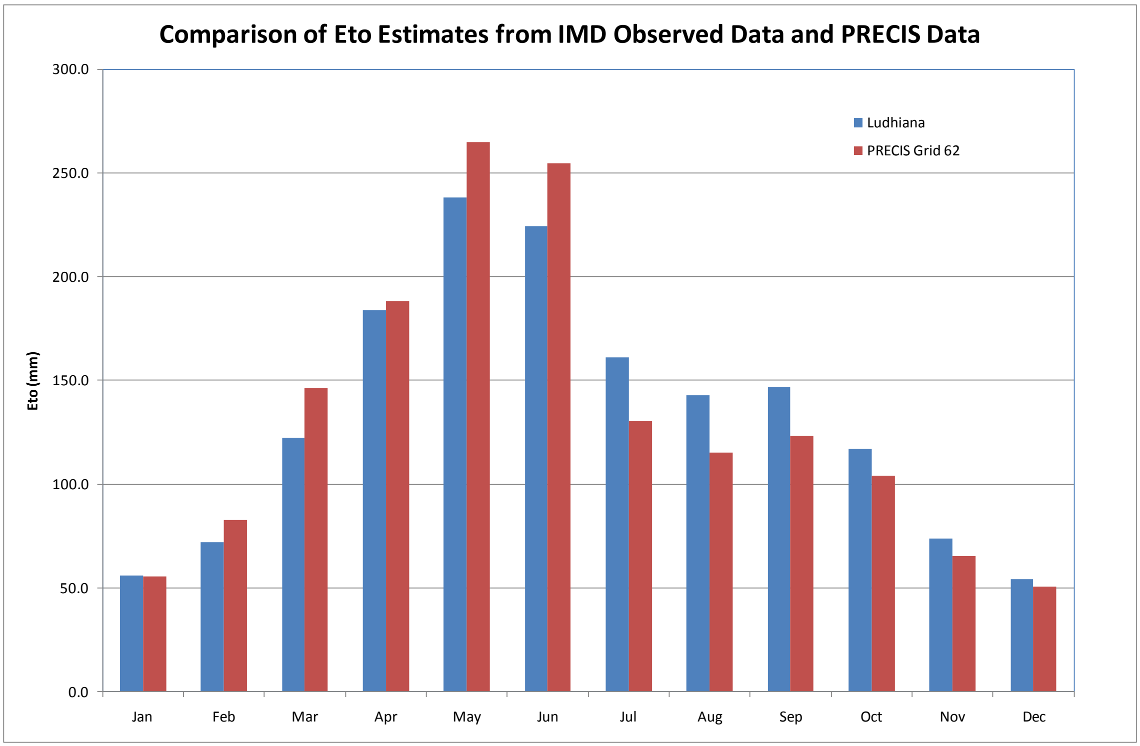


Figure 63 Comparison of ETo estimates from IMD data and PRECIS A1B baseline



305. **Conclusions:** The indications from the WEAP modelling are that a shift to directed seeded rice, along with improvement in irrigation efficiencies would improve the sustainability of groundwater use. Achieving sustainable groundwater use may require a reduction in rice area, or the reduction of crop consumptive use through the use of mulches, and improved irrigation technologies for some crops.

306. There exists some uncertainty over the water balance components at present. The observed rate of water table decline does not match with estimated groundwater overdraft. Further analysis of Punjab DWR groundwater resource potential and annual groundwater recharge data is required.

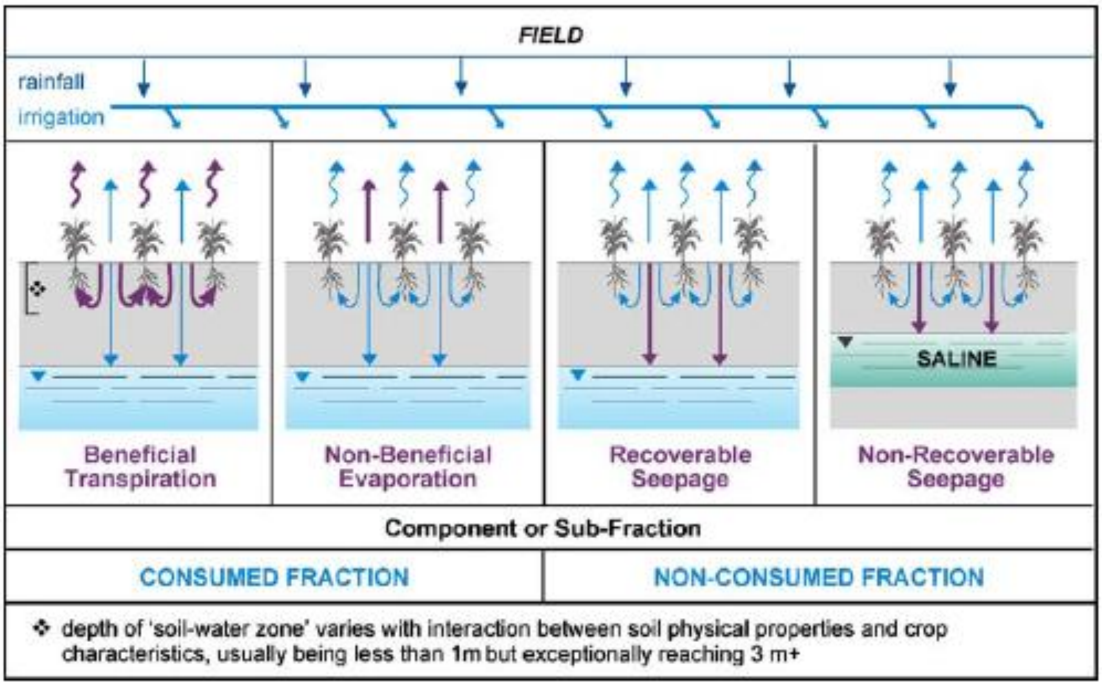
J. Irrigation Management Options

1. Conjunctive Management

307. When considering irrigation and groundwater resources it is necessary to identify the main fractions of water when it reaches a permeable soil[42] as shown in Figure 64. One of the potential consequences of improved irrigation water-use efficiency is further deterioration of groundwater resources due to shifting to spray irrigation from flood irrigation resulting in loss of return flows to aquifers. The water and energy saved is often then be used to extend the irrigation command area resulting in further loss of return flow to groundwater.

[42] Foster, S. et al. (2006a) Groundwater Management Strategies. GW-MATE Briefing Note 3. World bank.

Figure 64 Fractions of Consumed and Non Consumed Water



308. For irrigated systems, such as those in Punjab, only real savings to groundwater can achieved where modifications to irrigation and cropping-practices reduce the non-beneficial evapo-transpiration or non-beneficial discharges to saline water bodies. If more water savings are needed, than consideration should be given to explore options for switching to cultivation of less water-consuming crops or crop-strains (with shorter growing season, or suited to cooler periods when potential evaporation and transpiration are lower). In some areas it may be appropriate to ban cultivation of certain types of irrigated crops in critical groundwater areas. Amarasinghe et al. (2010)[43] in a study in Moga District of Punjab suggest that a reduction of the rice area and an intensification of dairy production with more green fodder can bring the groundwater depletion to sustainable limits.

2. Surface Water

309. The present Warabandi allocation system is good in its simplicity and equitability but there would appear to be scope to increase the efficiency. The system is supply led; available water is allocated without consideration of the type and growing stage of the crop. The allocation does not consider the groundwater 'conjunctive irrigation management' might offer opportunities for greater efficiency. At present the surface water is government managed and the ground water is private farmer managed. Conjunctive irrigation management requires a workable institutional arrangement to bridge the gap. In the Punjab the community or water user associations are poorly established and some mechanisms to bridge the gap would need to be developed. It is considered that irrigation management has to address the conjunctive use of surface and groundwater. This can probably be best managed by themselves approached by farmers themselves below the turnout.

3. Options for Conjunctive Surface and Groundwater Management

310. Present Management: surface water is managed almost entirely by Government. with groundwater largely unmanaged with a farmers free to install wells and pump indiscriminately. There is no linkage or coordinated planning or management of the surface and groundwater resources outside the farmer managed field channel system.

[43] Amarasinghe, U. A.; Smakhtin, V.; Sharma, B. R.; Eriyagama, N. 2010. Bailout with white revolution or sink deeper? groundwater depletion and impacts in the Moga District of Punjab, India. Colombo, Sri Lanka: International Water Management Institute. 32p. (IWMI Research Report 138).

311. **Management Options**: There are a many management variations but in general terms for Punjab there appear to be three ways forward:

1) **Regulation**: enforcement through State legislation controlling the number of wells and applying strict quotas on volumes pumped. Regulation could also cover cropping including restrictions or quotes on the area of rice grown and rotation of the permitted rice area are examples of regulation. Electricity rationing would also be a form of regulation.

2) **Financial Restrictions**: control the volumes of abstraction through pricing of electricity based on consumption (metering).

3) **Community Management**: aimed at creating community management of the water. It is proposed that this would include surface and groundwater. The community user associations would have responsibility for the sustainable management of the ground and surface waters within the lower level village canal systems. Federations of water users could work with Government agencies to monitor and assess groundwater levels. Some element of regulation would be required but this would be self regulation including agreed targets and plans to reduce groundwater. The Government would provide support packages to compensate for loss of income including incentives to change crops, subsidies for initiatives to increase yields and reduce consumption

312. Community managed water (surface and groundwater) would appear to offer the best possible management option with reasons including; (i) the difficulties for government to enforce controls and regulation of groundwater; (ii) the logistics of monitoring and controlling the estimated 2.3 million tubewells; (iii) conjunctive surface and groundwater management is best managed at the farmer level and (iii) the lack of political support for top down regulation..

4. Payments for Environmental Services (PES)

313. Payments for Payments for Environmental Services (PES) or ecological services (or Benefits) is the practice of offering incentives to farmers or landowners in exchange for managing their land to provide some sort of ecological or environmental service. These programmes promote the conservation of natural resources in the marketplace. Twenty-four specific ecosystem services were identified and assessed by the Millennium Ecosystem Assessment, a 2005 UN-sponsored report Notably, however, there is a “big three” which are currently receiving the most money and interest worldwide. These are climate change mitigation, watershed services and biodiversity conservation, and demand for these services in particular is predicted to continue to grow as time goes on. The 1997 Nature Magazine article estimated the annual value of global ecological benefits at $33 trillion, a number nearly twice the then global gross product.

314. PES programs are mutually beneficial contracts between consumers of ecosystem services and the suppliers of these services. The party supplying the environmental services holds the property rights over an environmental good that provides a flow of benefits to the demanding party in return for compensation. The concept is that environmental externalities can be solved through private bargaining between people who are willing to pay in order to reduce an environmental hazard and people willing to accept compensation in order to reduce the activity that generates the environmental burden.

315. For Punjab the application of PES is very relevant; there is a need to reduce groundwater extraction and farmers need some form of compensation or incentive to do this. The compensation could be direct financial grants ' for not to planting rice' or ' crop set aside' or ' planting trees to reduce salinity' or other incentives to reduce abstractions. Other options would be support incentives for increasing the efficiency of the water and agricultural systems including incentives for rice planting using new technologies, moving from rice to lower consumption crops, application of sprinkler/drip, increasing the efficiencies of the surface water systems etc. In India subsidies for irrigation and agriculture are very significant. To meet the needs of conservation it is recommended subsidies move from a blanket approach to more targeted to meet the specific needs of water conservation and reduction of groundwater abstractions. The magnitude of the groundwater problem indicates the need for a broad spectrum of measures including some level of regulation, moves to better efficiencies,

community to take up some level of self regulation and PES. PES may put some heavy burden on the state exchequer and mechanisms for cost recovery would have to be investigated.

5. Development of Block Level Management Plans

316. Block Level Management Plans are proposed to address the various requirement to meet sustainable water usages. The plans would be participative and developed by the Government and the Communities together. The Government would explain the issues facing the community based a conjunctive use assessment of surface and groundwater and the indicative climate change effects. The Government would set out targets and the necessary controls to meet sustainability including options to reduce groundwater abstraction, crop diversification. Options could include reduction in the rice area. change to shorter period and lower consumptive use crops, improved more efficient irrigation systems, drip sprinkler etc

317. To meet possible financial losses the Government would likely have to offer some appropriate mitigation packages based on the lines of PES (payment for environmental services) described above these. These would include price support for a wider range of crops, incentives to take up new irrigation or planting systems, minimum price support or financial support for set aside (non planting). Incentives to implement artificial recharge or water harvesting would also be considered. Improved power supply in return for agreements to reduce pumping may also be appropriate.

6. Other Management Initiatives

318. Sophisticated and modern equipment and methodologies should be adopted for seasonal weather forecasting as well short duration weather forecasting. Advisory weather forecasts should be made easily available to farmers.

K. Government Institutions

319. The current functions of the various water sector departments in their present form do not provide adequate operational basis[44] for implementing IWRM. Effective institutions are characterized by its stability and non fragmentation and non-overlapping of responsibilities, clearly defined but separated roles and is supported by strong and comprehensive, but flexible legislation, regulations, decrees, etc. and is lead by an "apex" body with clearly defined regulatory functions. The functions and tasks performed by the existing institutions do not lend support for integrating climate risk management in development as adaptive development. Therefore, transformation in roles/rules and relationship among the institutions is essential which could facilitate; (i) holistic water planning; (ii) review of financial instruments like targeted subsidies to support adaptation; (iii) participation of stakeholders in planning and management; (iv) strategizing environmental management and control measures ; (v) facilitate inter basin planning and management (vi) separation of roles like service provider-managers and regulators; (vii) conjunctive planning and regulation of Surface & Ground water h) monitoring of quality of water (viii) effective planning for Disaster (flood) management (ix) revenue recovery mechanism to be effective (x) post project performance evaluation (outcome & impact) is not being carried out flow and discharge measuring installations

320. A nodal agency for ensuring coordinated and integrated planning and management approach by various water centric institutions is needed. The role of the Bhakra Beas Management board could be widened to support research, planning and management of the upper catchment

1. Public/private/community roles and initiatives

321. ;In the change in context, it has become necessary to explore the potentials and risks associated with the state, private and community sector roles in water management and water service provision. The appropriateness of different public/private/community roles and responsibilities in different contexts needs to be addressed. Agenda of assistance /support needs to engage with these

---

[44] Source: (ADB TA NO. 7418-IND): Integrated Water Resource Management and Sustainable Water Service delivery in Karnataka- COMPONENT 1 report on Institutional Analysis and Proposed Reforms for IWRM-2010

roles and responsibilities to plan appropriate mixes of market- based, institutional and participatory approaches in management and service provision. Appropriate mix and linkage between roles, and the social acceptability of this mix and linkage, have to identified for each specific case.

322. **Community-based management** raises questions of capacity, financial management and participation. Long term sustainability and better demand- driven services and infrastructure have been the major objective of involving communities in the management of the resources. As support for community systems have moved from household wells to larger-scale and more complex community piped systems, so the challenges have grown. Operations and maintenance and financial sustainability have been the biggest challenges with community managed systems, followed closely by institutional and cultural challenges. Furthermore, recent experience suggests that as rural incomes increase, communities are demanding both higher levels of service and management arrangements that release them from day-to-day decision-making. Nevertheless, community involvement in water resource management remains a significant governance prerogative. Community consultations have indicated a willingness to participate in planning and policies for sustainability.

323. Key issues Governance reform in Punjab requires a devolvement of the **role** of the state as and owner and operator to regulator of various enterprises and services. In the case of water supply and sanitation, this might involve some element of corporatisation and privatization of water utilities and devolvement of rural water supplies to community management of village based water supply. In the case of irrigation it can range from cost-recovery and collection of water fees, to cooperative management, to hand over to community groups. In the case of catchment management the key issue is devolution of authority and community participation.

2. Catchment Management and Artificial Recharge

324. **Catchment management** It is widely documented fact that climate change will have impact on agriculture, soil and water conditions in the catchment /basin. Need for integrated catchment/basin planning is needed to assess the feasibility of models for soil and water conservation and also to evolve a robust climate sensitive agricultural support system. Catchment planning and management therefore provides a platform for the relevant institutions to participate in planning and management. The main problem that catchment management seeks to address is fragmentation. Using and managing water without reference to catchments results in fragmentation in a number of dimensions. Catchment management and artificial recharge activities need to be coordinated[45]. Key issues include:

i) **Geographical fragmentation:** A situation in which water is used and managed in different places without reference to other parts of a river basin (for example impact of upstream activities on downstream users)
ii) **Bureaucratic fragmentation** happens when different departments manage resources without reference to other departments – the “silo effect”
iii) **Social fragmentation** occurs when resources are managed in a technocratic way by a narrow group of professionals without reference to the knowledge, preferences and material interests of diverse stakeholders
iv) **Scalar fragmentation** happens when basin management at a macro-scale occurs without reference to its micro-level impacts, and where local scale initiatives occur without reference to cumulative basin-wide implications
v) **Political fragmentation:** A situation of a transboundary river basin settings where jurisdictions separate management along political rather than natural boundaries

325. Therefore, **Integration** is the key governance process to address fragmentation in managing water in its catchment context. Integrated water resource management has become the standard for good in this context. But one needs to identify the operational elements of IWRM for it to become an effective instrument for bringing water governance as there are number of perceived tensions, in catchment management through IWRM, between (i) Top-down and bottom-up approaches (ii) The

[45] Source: Adapted from the report on Water Governance : Lessons for Development Assistance: Volume 1: Overview Report/Australia Water Research Facility, AusAID /Australian Mekong Resource Centre-University of Sydney

holistic philosophy that lies behind integrated river basin management and the participatory ideal of decentred decision making (iii) The science-based approach that takes advantage of complex ecological knowledge, hydrological and water allocation models, and tools such as GIS, on the one hand, and community-based initiatives oriented to local knowledge on the other (iv) Catchment management institutions' role to allocate an increasingly scarce and finite resource (water) versus a catchment management institutional role to mobilise developmental resources and funds for new infrastructure to take yet more water off the river and (v) Prescriptive approaches to river basin management and institutional design and negotiated approaches, outcomes and institutional arrangements.

3. Equity implications of market and property rights

326. It is important to understand/analyze different equity implications of market-based approaches to water. Gender, poverty and indigenous dimensions of water regulation needs to be addressed with specific reference to the enhanced roles of markets and changing property regimes. Development outputs /outcome of NAPCC need to achieve a balance between efficiency, social equity and sustainability. Equity is a key concern for water related development assistance. Though many water resource development interventions have been premised on increasing the supply of water to people and for food, there are raising disparities in water access between the rich and poor within and between the states.

Human intervention, whether through technology or governance, alters the allocation of water. There is no 'natural' distributive justice in water availability due to the significant variations between seasons, upland and lowland areas, and regions. Yet human regulation re- distributes water according to the economic and social objectives of those who control structures at a given scale. Negotiation over water distribution and equity between various actors, whether they be neighbours sharing a well or states sharing a large river, are shaped by underlying issues of power, culture and values. Negotiation and equitable outcomes thus vary greatly according to societal context. Water quality wherever and whenever available, is an issue.

327. The way in which **water rights** are articulated through a country's governance structures (whether through law or custom) has significant implications for equity. There is always tension (sometimes creative) between the considerations of water as an economic good and the view of water as first and foremost a human right. Prioritizing water as an economic good often involves the privatisation of water rights. When water is seen as a basic human right (and it is recognized as such in international law), it is more likely to remain in public ownership. Property rights paradigms often reflect the dominance of one of these positions without appropriately defining a balance between the two.

328. **Water equity** can also be considered with reference to competition between sectors. Agriculture remains the largest water user in the basin. Yet water supply for agriculture is coming under increasing competition from other water uses, such as industry and urban water supply, as societies and economies change. Those engaged in agriculture, and other natural resource based livelihoods may be vulnerable to re-allocations of water to other sectors, or changes in the timing or quality of water availability. Whilst agriculture may not be the most economically profitable use of water, however, the provision of adequate supplies of water for agriculture is critical to food security next only to drinking water.

329. The nature of water is such that it can be easily captured and diverted, and as such water can be tapped, stolen and systems of regulation subverted. Whether at a community or national scale, for equity to be maintained in a system it requires a high degree of social acceptance in order to minimize the cost of regulation and enforcement. In the same way, reform to any system of water governance also requires a high degree of social acceptance to ensure conflict is avoided. To have some sort of reallocation of water, for example towards a more equitable, efficient or sustainable arrangement, requires negotiation, compensation, and a transition process that is both iterative and socially acceptable.

4. Effective Information Systems for Good Water Governance

330. In the present institutions, participation in decision making is a means to an end, and the goal of informed decision-making requires good & reliable quality information on a range of issues, spatial, technical, social, economic, legal and institutional. This necessitates (i) establishment of an integrated data and information unit and basin level knowledge centers; (ii) capitalization of knowledge emerging form various initiatives like the hydrology project supported by the World Bank,land use information developed under different schemes; (iii) developing climate related information archives to promote climate literacy among the various stakeholders in general and village panchayat leaders in particular (iv) development of decision support systems for effective water management; (v) establishment of updated design parameters to the impact of extreme events due to climate change; and (vi) development of data base related to water and climate for carrying out climate research

5. Knowledge and Human capacity

331. Knowledge and human capacity[46] are critical to implementing successful water resource development and management initiatives within the framework of Integrated Water Resources Management (IWRM). New skills and capacities within water management institutions are critically important—at a time when various forces are supposedly weakening governments' capacities to attract and hold people with this expertise. While capacity development focuses on actors (individuals and institutions) but includes their environments (systems) that affect their capacity; Capacity development should not be conceived as necessarily involving formal projects or activities with specific capacity development objectives. Capacity development also takes place through learning by doing, participation, observation, comparison of experiences, and a host of other informal activities. The potential area of work in capacity development extends across a range from individual, through organizations to systems. Within each grouping separation can be made into capacity development in areas of self, social (interactions between individuals) and methodological. However, the underlying assumption is that the capacity building initiative shall help towards new and stronger institutional capacity for management, service delivery, resource generation and management.

6. Strengthening of Ground and Surface water Institutions

332. The institutional framework includes government institutions, local authorities, private sector, civil society organizations, farmers' organizations and other community-based organizations. Capacity building will be needed at each of these levels either through the development of existing water management arrangements or by forming new ones. Some particular issues requiring capacity building within the institutional framework for groundwater include the following:

i) There is a need to link the current approach to groundwater resource assessment with more hydrogeologically sound approaches. A way forward could be to maintain the current practice of collecting water resources data at the smallest administrative units (e.g. block) but when aggregating these data use hydrological based divides (topographic divides and hydrogeologically connected aquifers units). A precursor to this approach would be an improved understanding of the hydrogeological system particularly concerning regional aquifer flows for shallow and deep aquifers and on the nature of groundwater-surface water interactions. This approach would also require relevant staff at district level to work together to develop these aggregated datasets supported by a wider state body or in the case of interstate water resources a central government agency.
ii) Different methodologies for quantifying groundwater recharge should be trialed in pilot areas to confirm the viabilities and improve the current methodology for groundwater resource assessment (Water Level Fluctuation method). These improved methodologies could subsequently be applied to the new hydrogeologically sound areas of assessment discussed in the previous bullet.
iii) There is a need to separate water resources management functions (overall management of water resources as a whole) from service delivery functions (irrigation, hydropower, water supply and sewerage) to avoid conflicts of interest and encourage commercial autonomy.

[46] Capacity is the ability of actors (individuals, institutions, and societies) to perform functions effectively, efficiently and sustainably. Capacity is the power of something (person, institution, system) to perform or produce.

Capacity building will be needed to support effective water resources planning of surface water and groundwater.

iv) Effective and early public participation approaches will be required particularly with farmers' organizations to ensure that they are involved in the planning and decision-making processes. Capacity building of Water Users Associations and Panchayats will be particularly important to ensure take-up of new approaches to groundwater use.

7. Capacity Building and Development

333. Based on state consultations a summary of the key capacity building areas towards institutional strengthening[47] , water resource and user institutions development are presented in Table 41

Table 41 Key Areas for Capacity Building

	WATER RESOURCES DEPARTMENT
1	○ Water Management practices for sustainable agriculture ○ Volumetric supply of water and installation of measuring devises ○ Basics of Farmers Managed Irrigation Acts and formation of WUA ○ GIS application ○ On New Institutional arrangements and the roles to be played by WRD ○ Community involvement in managing irrigation infrastructure ○ Preparation of thematic maps for the selected basins ○ Knowledge on and Utilization of modern equipments for Topographical and cadastral survey ○ Modern design on irrigation structure and coastal structure ○ Budgeting. accounting and financial management including fund-flow arrangements ○ Environmental assessment and redressal systems in the social & environmental assessment framework ○ Maintaining MIS ○ O & M of the irrigation assets and allocation of adequate funds ○ Project Planning, Monitoring and Evaluation ○ GIS Applications in Irrigation ○ Modern Survey Techniques (Total Station and LADAR- Laser Detection and Ranging ○ Environmental Impact Assessment & Management (EIA/EMP of irrigation projects) ○ Project Economics ○ Procurement & Contract Management (including procurement procedure) ○ Procurement/ Tendering ○ Planning of Irrigation Projects ○ Modern Irrigation Techniques like Sprinkler/Drip Irrigation ○ Benchmarking of Irrigation Projects ○ Water Use Efficiency/Water Auditing of ○ Productivity Enhancement in Command Area ○ Design of Dams ○ AutoCAD ○ Land Acquisition and Encroachment Issues ○ Modern Construction Technology and Techniques ○ Quality Control of Construction ○ Revenue Recovery ○ Revenue Recovery and Related Issues ○ Canal and Drainage Hydraulics ○ Mirco-distribution Network, Plan & Design ○ Preparation of Operational Plan for Irrigation Projects ○ SCADA - Canal Automation ○ Design & Operation of Canal Flow, Flow Measurement and Control Structures ○ Dam Safety Aspects
	OTHER DEPARTMENT
	○ Integrated Farming ○ Adoption of Micro irrigation technology ○ Promotion of Hybrid vegetable and Horticultural crops ○ Promoting fodder cultivation ○ Seed production and seed certification

[47] Main goals of institution strengthening is the strengthening of management and therefore capacity building areas must cover management issues.

	○ Agro-climatic zones and agronomy ○ Pest Management
	COMMON TO ALL DEPARTMENTS
	○ Concept, principles and practices of IWRM ○ Basin approach in Planning and Implementation ○ National and State Acts & Rules ○ Formation and functioning of RBO s ○ Legal Issues and Related Software ○ Legal Issues and Use of LIS (Legal Information System) ○ Human Resource Management/Strategic Human Resource Management ○ Right to Information ACT ○ Leadership, Motivation and Team Building ○ Developing Communication Skills ○ Time, Stress and Conflict Management ○ Participatory Irrigation Management ○ Gender Issues and their Integration ○ Management of Organizational Change ○ Building Organizational Culture for Performance ○ Competency Mapping and Management ○ Public Private Partnership

X. CLIMATE CHANGE SCENARIOS

A. Introduction

334. Understanding the effects of future climate under the influence of global warming requires the use of climate simulation models, run with a range of possible emission scenarios and incorporating the uncertainty that exists in climate model forecasts. Scenarios are used in estimating the probable effects of one or more variables and can support the decision making processes for what are the most appropriate adaptation requirements, and are an integral part of situation analysis and long-range planning. In this regard, future climate scenarios were developed based on assumptions on the change of drivers that would influence the climate system; particularly change in the atmospheric concentration of greenhouse gases which may vary under different pathways of the world development in the future. Long-term future climate projections provide the basis for assessment of climate change impacts on certain sectors in specific areas. The climate state obtained by incorporating an emission scenario in global and regional climate models is called a climate scenario, while the difference between a future and current or recent climate state resulting from consequent changes in atmospheric composition is called a climate change scenario.

335. The climate change impacts on the hydrology of the Sutlej basin are mainly concerned with the shrinkage of glaciers in the Himalayas, which are melting faster than they are being replenished with new snow, providing temporarily a higher base-flow. This increased melt-rate is controlled by elevated temperatures and deposits of dark soot particles on the snow and ice, which decreases the albedo, and hence increases the amount of incoming solar radiation that is being absorbed. The soot loading of the atmosphere ("*brown haze*") also impacts the temperature profile of the atmosphere and the precipitation patterns in the region.

336. Until recent years, black soot-induced reduction of snow albedo (reflecting power) and its contribution to glacier retreat in the Himalayas have only received sparse attention, and there is a need for more extensive experimental (field) data.

337. Gridded data for precipitation and temperature exist for the region, at resolutions down to 25km. Given that the topography of the Sutlej basin is very rugged, this can be seen only as a rough approximation. In this study the IMD gridded dataset has been utilised for observed precipitation.

B. Summary of Observed Changes to the Present Time

338. At Ludhiana, mean daily temperatures range from a low of about 13^{o}C in January to a high of about 33^{o}C in June. May and June are the hottest months with mean daily maximums close to 40^{o}C. The mean daily temperature range is typically about 12^{o}C. A maximum range of 15.5^{o}C occurs in May. The minimum range of about 8^{o}C occurs in July and August. Relative humidity is at its lowest in May, averaging 31%, and peaks in August at 76%. The climatic norms at Ganganagar which represents the climate features in the southwest part and follows a very similar pattern to those at Ludhiana. Mean daily temperatures are a few degrees higher at Ganganagar during the summer months, and the mean daily temperature range is higher than at Ludhiana, being 18^{o}C in April and 20^{o}C in November. Relative humidity at Ganganagar is lower than at Ludhiana, and wind speeds significantly higher. Solar radiation is marginally higher than at Ludhiana. The climatic norms combine to produce potential evapotranspiration that is significantly higher than at Ludhiana.

1. Rainfall

339. Drought duration varies significantly across the lower basin in any particular year. There is an indication that droughts in the southwest of the lower basin may be becoming more extreme.

2. Snow:

340. Although snow falls in the Western Himalayas are reported to be reducing no specific significant trend was observed in the Sutlej . Average snow falls are shown in Figure 65. Studies by ICIMOD show a small rising trend 2000 to 2010 as shown in Figure 66 .About 65% of the basin area is covered with snow during winter, which reduces to about 11% after the ablation period. There are already reports of earlier melts especially at lower levels.

3. Glaciers

341. There is good evidence and local report of glacier decline especially in the lower catchments. The situation in the higher catchments are less clear; visual indications indicate quite large variations with some glaciers showing very high levels of loss and others quite robust with little change.

4. Flows

342. Analysis of inflows to Bhakra show no significant trend of increasing or decreasing flow which tends to confirm the assessment of balancing of reduced and increased melts from the lower and higher parts of the catchment

Figure 65 Average Snow Fall in the Sutlej Basin

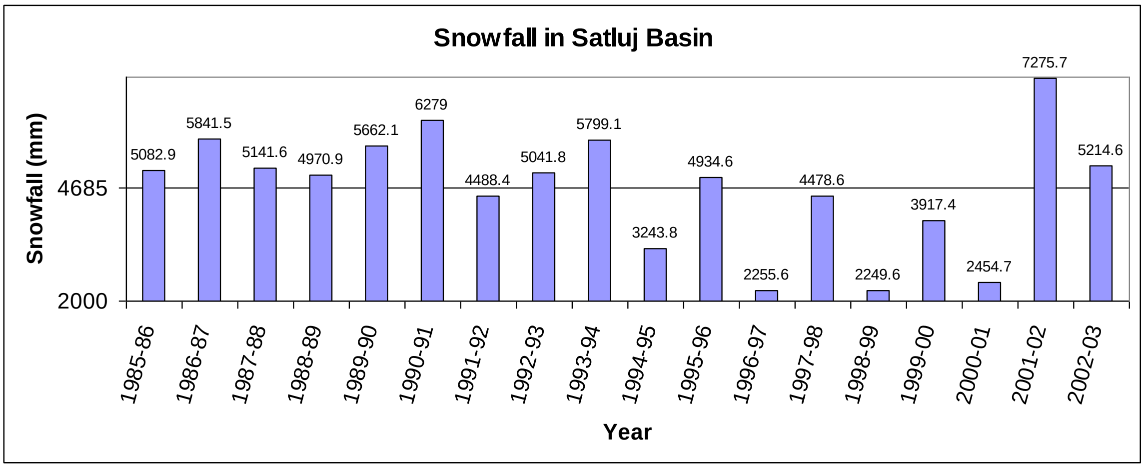
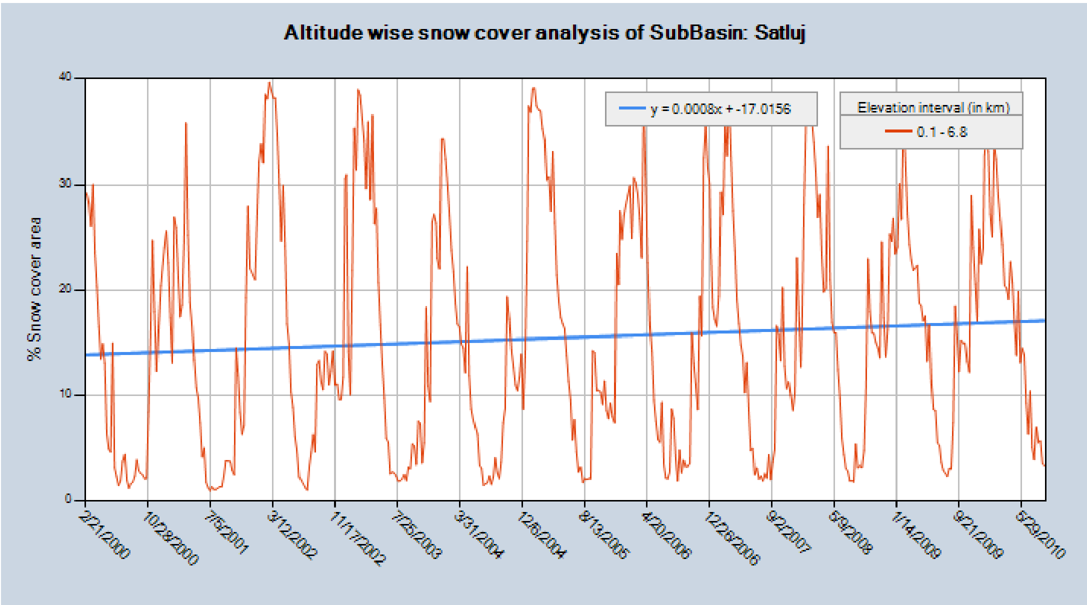


Figure 66 Altitude Wise Snow Cover



C. Current Awareness of Climate Change

343. Amongst the Government officials there is a mixed level of understanding and beliefs in climate change. In the India context annual variations are normal and there is a general lack of real statistical information to direct the climate change dialogue one way or another. Temperature changes are generally difficult to detect. In Himachal Pradesh, however, some of the lower level tributary rivers are already losing glacier contribution and agriculture changes are clear to see; for example apple cultivation has become less viable at lower levels and has moved to higher elevations.

344. The Participatory Rural Appraisal identified a strong perception of climate change. 100% of farmers questioned felt there were climate impacts; cold weather periods were perceived to be getting shorter, the cold period was previously 4-5 months is reducing to 1-2 months with an adverse effect on the winter wheat yield which has reduced by 25%. All those questioned felt that there was a reduction in rainfall with more erratic rainfall patterns. The occurrence of unseasonal rainfall and especially showers during the harvest period in November is affecting the yield at maturity. It also decolourises crops. In this respect improved weather forecasts will not be useful as pre mature harvest will lead to reduced yield

345. Other impact reported includes the occurrence of hail stones. This used to be in March but occurred in November December in 2010 and caused major damage to crops (~ 25% -40% loss). Farmers noted a delay in the start of the monsoon which appeared to be 15-20 days later than before.

D. Relevant Climate Studies and Findings

346. A study by the Department of Agronomy, Punjab Agricultural University, Ludhiana (Mathauda, 2000) found that the warming projected under climate change will have a negative effect on rice yields. Elevated ground level ozone concentration will also have a strong detrimental effect on crop yields (rice, wheat). New scientific evidence shows much stronger interactions between the carbon cycle, low-level ozone and atmospheric aerosols than previously thought, strengthening evidence for linking action to curb different types of pollution. [Betts et al, 2007]

347. Black carbon and its impact on glacial melt and atmospheric warming is researched by a number of groups in India, e.g. at IISC/CAOS aerosols and their impacts on climate are studied by Bala, Chakraborty and Satheesh.

348. **The IPCC AR4** reported that there would be an increase in temperature under almost all scenarios. Under the A1B scenario there would be (i) an increase of 3.3 °C by the end of 21st Century; (ii) lesser warming JJA by about 2.7 °C and warming would increase northward within the region. For precipitation under A1B; (i) a decrease in DJFI but increase during rest of the year; and Land-Sea T anomaly to be less prominent in controlling Monsoon. The results have been widely circulated and disseminated.

349. Simulations carried out with PRECIS using boundary conditions from the HADCM3 GCM for future climate scenarios indicate an all-round warming over the Indian subcontinent associated with increasing greenhouse gas concentrations. The annual mean surface air temperature rise by 2030s ranges from 1.7°C to 2°C in three simulations carried out.

350. INCCA 2010[48] have presented a number of projections very similar to the present study. The methodologies presented by the INCCA report have used the same PRECIS simulations and are very similar to the present study.

E. The PRECIS Model

351. Climate models are mathematical models used to simulate the behaviour of climate system. They incorporate information regarding climate processes, current climate variability and the response of the climate to the human-induced drivers. These models range from simple one dimensional models to complex three dimensional coupled models. The latter, known as Global Circulation Models (GCM), incorporate oceanic and atmospheric physics and dynamics and represent the general circulation of the planetary atmosphere and ocean. The GCMs are usually run at very coarse grid (about 3° x 3°) resolution (dimension of a grid cell of order several 100km), whereas the processes that are of interest for studies such as this one, such as precipitation, are highly influenced by the local features namely orography and land use, and even cloud-microphysics. These local characteristics are not properly represented at the coarse scale of GCMs and contribute to prediction errors on the impact of climate change at the sub-grid scale. Therefore, these GCMs are strengthened with the incorporation of local factors and downscaled, in general with a grid resolution of about 0.5°x0.5° or

[48] INCCA Indian Network for Climate Change Assessment 2010 MoEF

less. The downscaling can be of dynamic or statistical type. These models are referred to as Regional Climate Models (RCM) and improve the quality of climatic prediction for specific local areas.

352. A RCM is a model of the atmosphere and land surface which has high horizontal resolution and consequently covers a limited area of the earth's surface. A RCM cannot exist without a 'parent' GCM to provide the necessary inputs. The RCMs provide an opportunity to dynamically downscale global model simulations to superimpose the regional detail of specified region. RCM provide climate information with useful local detail including realistic extreme events and also they simulate current climate more realistically.

353. A regional climate model is a comprehensive physical high resolution (~50km) climate model covering a limited area of the globe. The model Includes the atmosphere and land surface components of the climate system including representations of the key processes within the climate system (e.g., cloud, radiation, rainfall, soil hydrology).

354. **Advantages** of regional climate models include (i) highly resolved information; (ii) physically based character; (iii) many variables; and (iv) better representation of the mesoscale and weather extremes than in GCMs.

355. **Disadvantages** of regional climate models include (i) computational expensiveness, particularly for long runs; (ii) lack of two way nesting (feedback with the forcing GCM input); (iii) dependence on usually biased inputs from the forcing GCM; (iv) errors in the GCM fields that could result in errors in the regional climate scenarios; and (v) availability of fewer scenarios.

356. **P**roviding **RE**gional **C**limates for **I**mpact **S**tudies (PRECIS) is an atmospheric and land surface model of limited area and high resolution which is locatable over any part of the globe. PRECIS is the UK's Met Office Hadley Centre portable regional climate model, developed to run on a Linux PC with a grid resolution of 0.44° x 0.44°. The high-resolution limited area model is driven at its lateral and sea-surface boundaries by output from global coupled atmosphere-ocean (HadCM3) and global atmospheric (HadAM3) general circulation models. PRECIS captures important regional information on summer monsoon rainfall missing in its parent GCM simulations. Dynamical flow, the atmospheric sulphur cycle, clouds and precipitation, radiative processes, the land surface and the deep soil are all described and lateral boundary conditions (LBCs) are required at the limits of the model's domain. Information from every aspect may be diagnosed from within the model (Noguer et al., 1998). **P**RECIS can **b**e appli**e**d easily to **a**ny are**a** of the globe to generate detailed climate change predictions and is used for vulnerability and adaptation studies and climate research.

F. Regional Climate Scenarios for India Using PRECIS

357. Indian RCM PRECIS has been configured for a domain extending from about 1.5°N to 38°N and 56°E to 103°E. The IPCC SRES A1B Scenario with boundary conditions produced from the Hadley Centre HADCM3 GCM with the Q14 member of the QUMP (**Q**uantifying **U**ncertainty in **M**odel **P**redictions) ensemble for the time slices of present (1961–1990), mid-century (2021-2050) and end-century (2071–2100) has been made available by IITM Pune. The SRES A2 and B2 scenarios are available for the baseline and end of century.

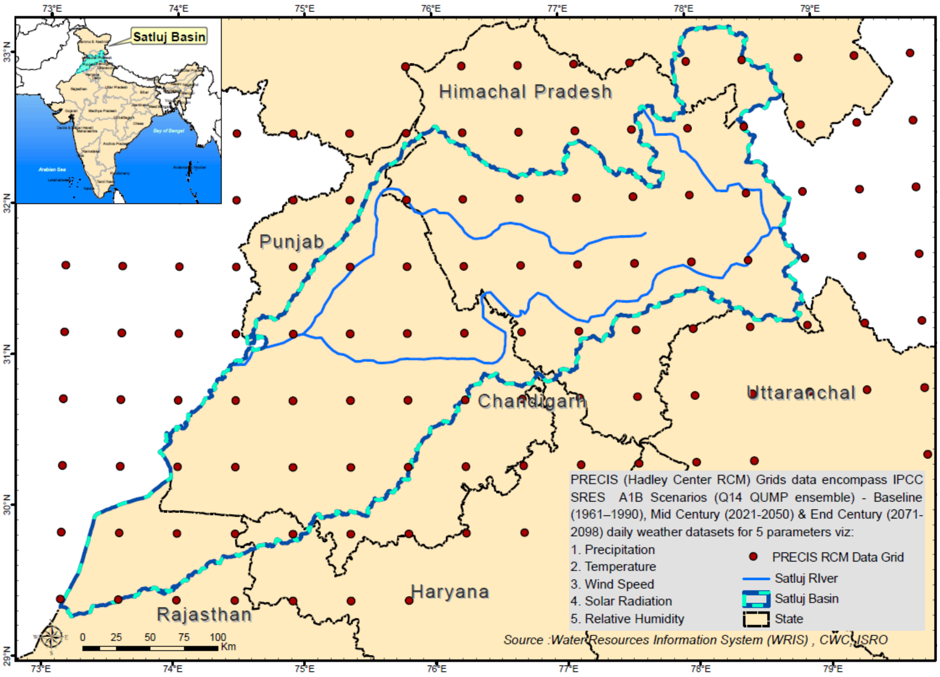
Simulations from a seventeen-member perturbed physics ensemble (PPE) produced using HadCM3 under the Quantifying Uncertainty in Model Predictions (QUMP) project of Met Office Hadley Centre have been used as LBCs for 138 year simulations of the regional climate model PRECIS. The QUMP simulations, comprise 17 versions of the fully coupled version of HadCM3, one with the standard parameter setting and 16 versions in which 29 of the atmosphere component parameters are simultaneously perturbed (Collins et al. 2006). Thus far three scenarios have been run with the Indian RCM PRECIS.

G. Scenarios for Sutlej Using PRECIS

358. For climate change projections in the Sutlej basin, output from one member of the QUMP ensemble (Quantifying Uncertainty in Model Predictions) downscaled using PRECIS was available. Apart from the baseline (1961-1990) which represents the present, the following two time slices for the

future are being investigated: mid-century (2021-2050) and end-century (2071–2100); all three time slices use the SRES scenario A1B. The PRECIS grids for the Sutlej are shown in Figure 67.

Figure 67 Precis Data Grids for the Sutlej Basin



359. In the next couple of years, new, more sophisticated climate model output will become available in CMIP5 (Coupled Model Intercomparison Project Phase 5) that will be part of the IPCC's AR5, it is likely that the new models will give an improved monsoon description.

1. Temperature

360. The Sutlej river basin is partly located in the Indian state of Punjab. The annual temperature range in Punjab is from -2 to 40 °C (min/max), but can reach extremes of 47 °C in summer and -5 °C in winter. Climatically, Punjab has three major seasons: Hot season (April to June) when temperature rises as high as 43 °C. The rainy Monsoon season (July to September) is from July to September The monsoon onset tends to be quite late. Cold season (October to March) when minimum temperature can fall below 0 °C

361. The temperature range (max & min) for the basin from downscaled QUMP results for the A1B emissions scenario are shown in Table 42.

Table 42 Temperature Projections, A1B

	JF	MAM	JJAS	OND	Annual
Mean daily maximum					
1970s baseline	5.3	19.7	25.0	11.0	15.3
2030s	7.0	21.8	26.6	12.3	16.9
2080s	9.8	24.4	29.3	15.5	19.8
Mean daily minimum					
1970s baseline	-9.6	5.6	11.9	-7.1	0.2
2030s	-2.9	12.0	13.8	-4.3	4.7
2080s	0.1	15.0	16.7	0.4	8.1

362. Figure 68 shows the change in temperature distribution across the Sutlej basin, for mean daily maximum and minimum temperatures. The whole basin is projected to warm significantly, with

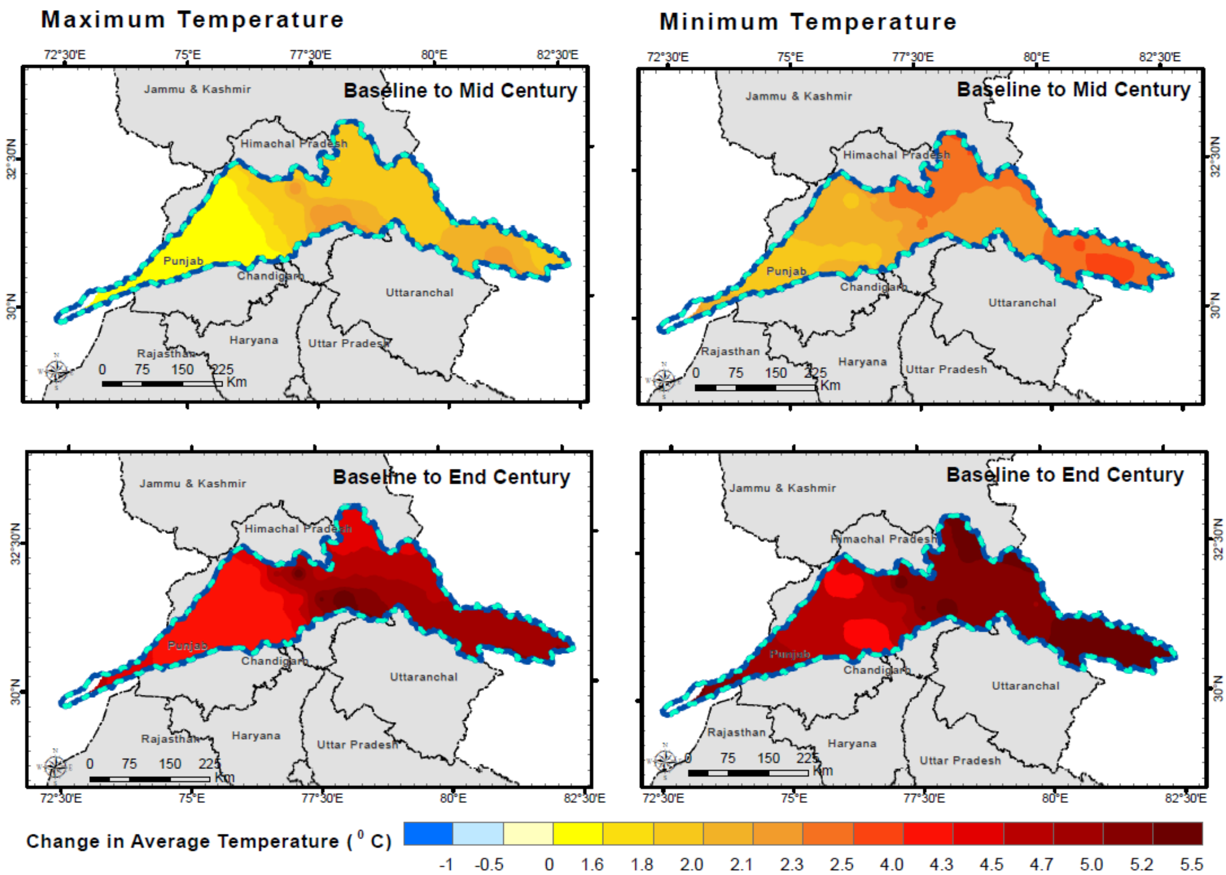
minimum temperatures rising most pronouncedly in some of the high altitude regions in the north and east of the basin.

363. The PRECIS model has also been run by IITM Pune for the A2 and B2 emissions scenarios. Table 43 below presents a comparison of the changes in mean daily maximum and minimum temperatures projected with the A1B, A2 and B2 scenarios for the 2080s. Changes in maximum temperatures projected under the A1B and A2 scenarios are similar. The B2 scenario produces much lower temperature increases. The A1B scenario produces significantly higher changes in mean daily minimum temperatures than does the A2 or B2 scenarios. It is interesting to note that under the A1B scenario the projected increase in minimum temperatures in the winter months is double that of the maximum temperatures. The changes in minimum temperatures projected under the A1B scenario would have a significant impact on snow accumulation and glacial melt in the upper Sutlej. The distribution of temperature changes under the A2 and B2 scenarios is very similar to that of A1B.

Table 43 Comparison of projected changes in temperatures, A1B, A2 and B2 scenarios, 2080s

Mean daily maximum temperatures					
Scenario	**JF**	**MAM**	**JJAS**	**OND**	**Annual**
A1B	4.5	4.7	4.3	4.5	4.5
A2	5.0	4.1	4.1	5.2	4.6
B2	2.9	1.8	2.9	6.1	3.4
Mean daily minimum temperatures					
A1B	9.7	9.4	4.8	7.5	7.9
A2	5.5	5.1	4.0	5.6	5.0
B2	3.7	3.0	2.9	7.2	4.2

Figure 68 Change in Mean Daily Temperatures



Source: PRECIS RCM daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune

2. Precipitation

364. The river basin receives most of its rain during the Monsoon season, which starts in June/July. The present average annual rainfall ranges between 960 mm sub-mountain region and 460 mm in the plains. Table 44 shows the seasonal average precipitation across the Sutlej basin. The whole basin is projected to receive increased precipitation with most of the increase located in the western parts of the basin, which may receive up to 50% more precipitation by the end of the century compared to the current climatological baseline. The least increase will be experienced in the very eastern upstream parts (located mainly in China) and a small tongue-like region protruding into Pakistan

Table 44 Projected Precipitation, A1B Scenario

	JF	MAM	JJAS	OND	Annual
1970s baseline	126	165	572	155	1018
2030s (A1B)	122	181	659	194	1156
2080s (A1B)	142	177	746	202	1267

365. A comparison of the seasonal changes in precipitation projected under the A1B, A2 and B2 emissions scenarios for the 2080s is given in Table 45. The A1B scenario results in a significantly higher increase in precipitation that does either the A2 or B2 scenario. In all scenarios the greatest increase in precipitation is in the monsoon season. It is of interest to note that the seasonal pattern of increases is different between the A1B and A2 and B2 scenarios. The A2 and B2 scenarios produce higher increases in the MAM season and a reduction in precipitation in the OND season.

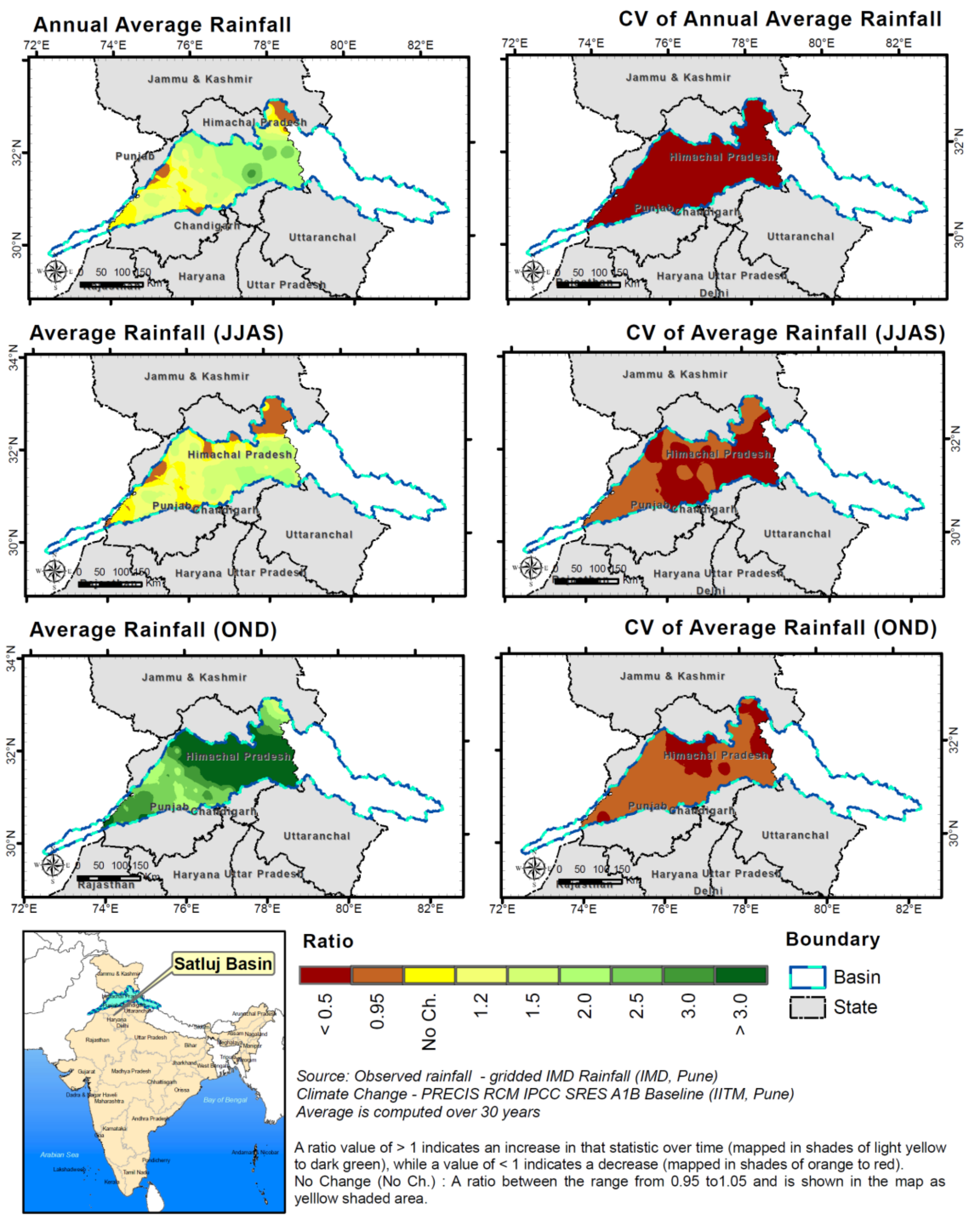
Table 45 Projected changes in seasonal precipitation, A1B, A2 and B2 scenarios to 2080s

Scenario	JF	MAM	JJAS	OND	Annual
A1B	16	12	174	27	249
A2	6	25	79	-13	98
B2	20	51	77	-18	131

366. PRECIS has some bias in precipitation calculation both annually and seasonally, and this bias differs across the basin. Figure 69 presents the ratios of PRECIS A1B data to IMD data annual and seasonally for the baseline period. In the lower basin the bias is not too significant, but in the mountainous parts of the basin, and particularly in the east the bias is very significant, and would influence the results of hydrological simulation modelling. Also of note is the fact that the variance in PRECIS simulated data is very much lower than that in observed data, and again there are implications for hydrological modelling. It is apparent that bias adjustment of precipitation data would be required prior to its use in any hydrological modelling. Similar bias exists in A2/B2 simulations of baseline climate.

367. The pattern of projected annual and seasonal changes in precipitation under the A1B scneario shown in Figure 70 and Figure 71 indicate that the greatest changes in precipitation occurr in the foothills of the Himalayas, where precipitation is highest. Very significant increases in precipitation are projected, being around 25% by mid-century in the foothills, where bias in PRECIS simulation is highest also. The pattern of projected changes in precipitation under the A2 and B2 scenarios is quite similar to that of the A1B scenario.

Figure 69 Comparison of PRECIS A1B Baseline Precipitation with Observed



Source: Observed rainfall - gridded IMD Rainfall (IMD, Pune)
Climate Change - PRECIS RCM IPCC SRES A1B Baseline (IITM, Pune)
Average is computed over 30 years

A ratio value of > 1 indicates an increase in that statistic over time (mapped in shades of light yellow to dark green), while a value of < 1 indicates a decrease (mapped in shades of orange to red).
No Change (No Ch.) : A ratio between the range from 0.95 to1.05 and is shown in the map as yelllow shaded area.

Figure 70 Percent Change in Average Precipitation Across Sutlej Basin

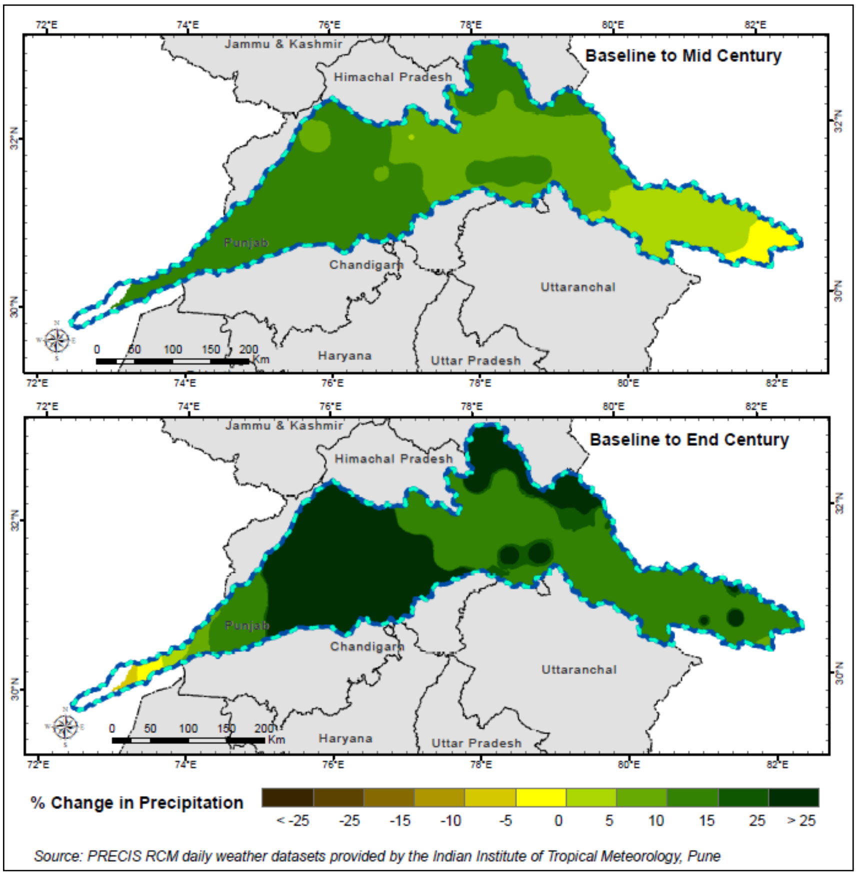
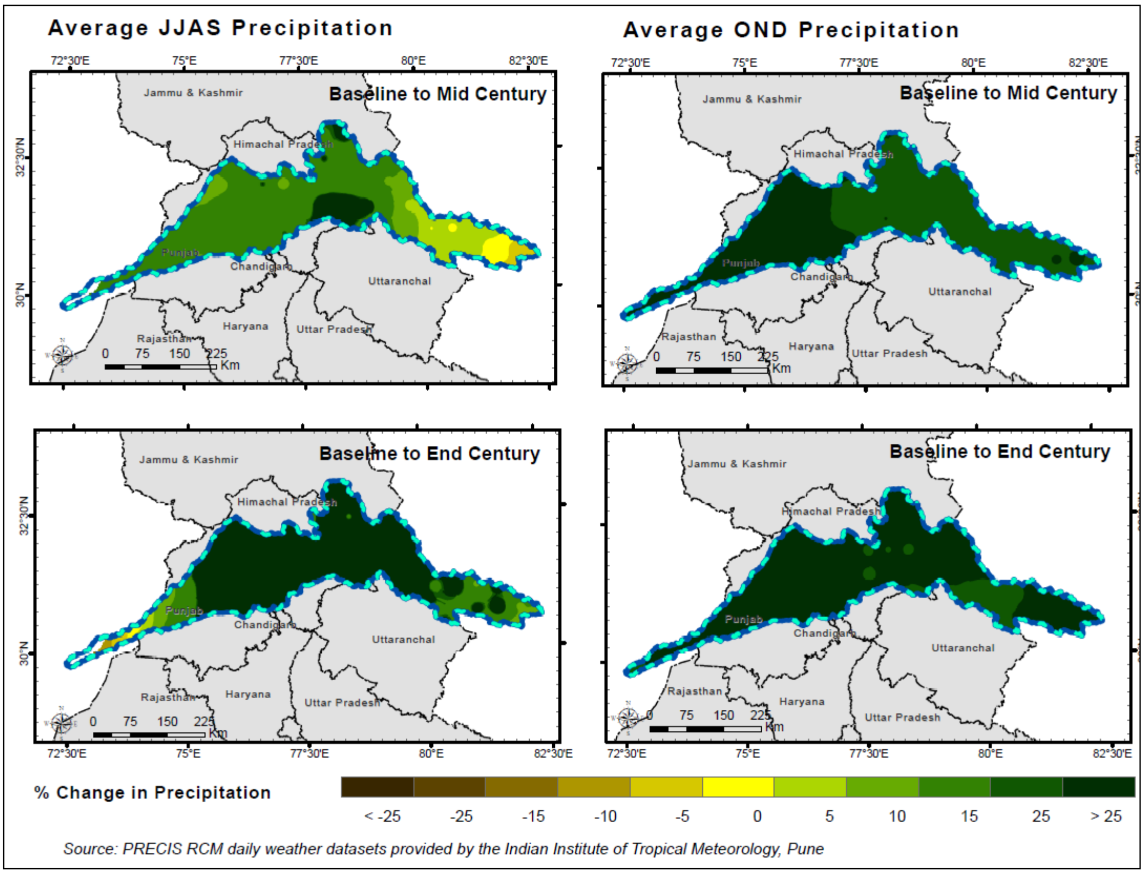


Figure 71 Percent Change in Average Monsoon Precipitation Across Sutlej Basin



3. Precipitation intensity

368. Another important factor of rainfall is its intensity – very heavy rainfall events can lead to increased erosion and flooding. The number of days with heavy rain has been analysed in the downscaled QUMP run (A1B) (it is important to note that heavy precipitation events are often underrepresented by climate models (both GCMs and RCMs). Results are shown in Figure 72 and Figure 73.

369. Both at the 100mm/day and 150mm/day level, small increases are projected to occur in the central region of the basin, and some regions could see the number of such days double from about 3/year to 6/year by the end of the 21st century. Mountainous regions are less affected.

Figure 72 Changes in number of days per year with more than 100mm of rainfall

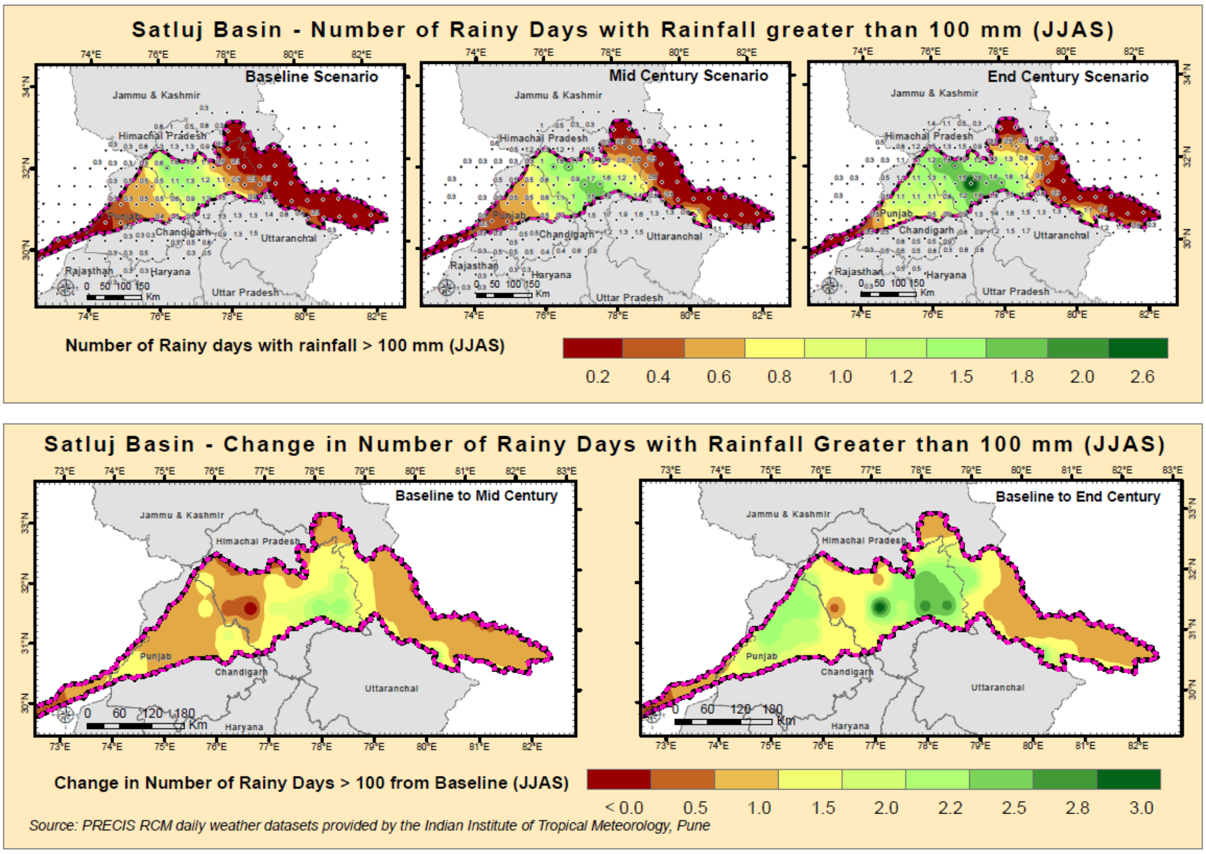
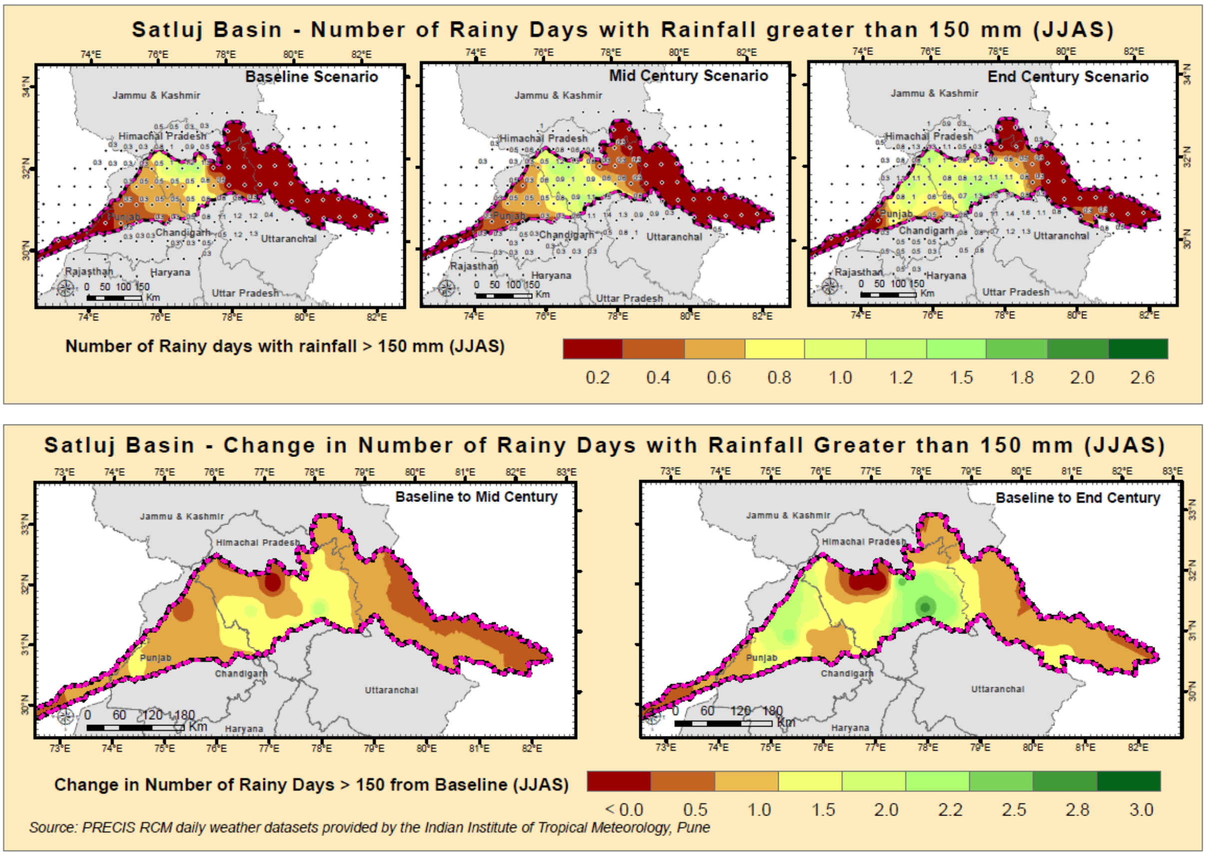


Figure 73 Changes in number of days per year with more than 150 mm of rainfall

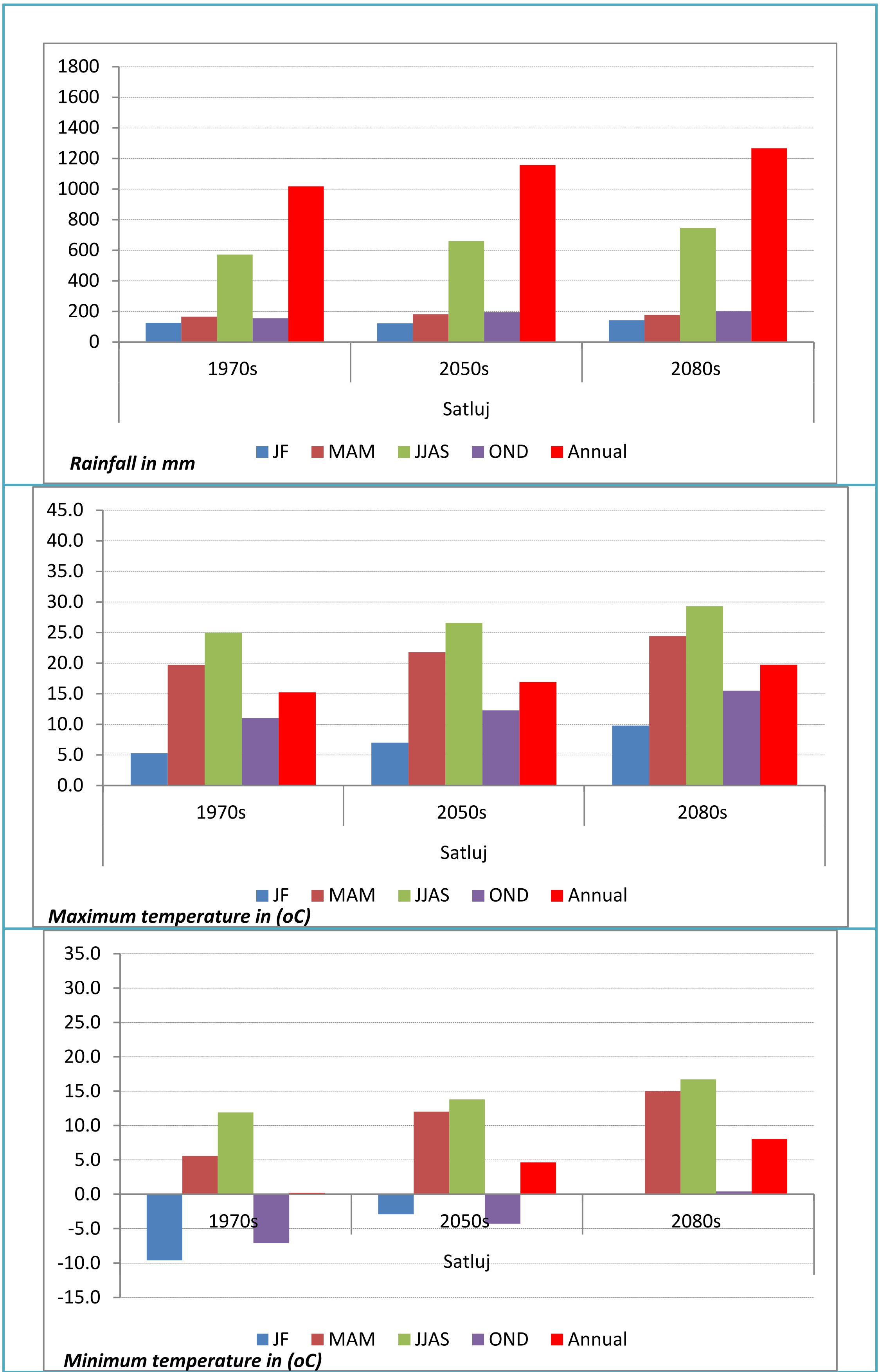


4. Combined Temperature and Rainfall

370. Figure 74 gives the changes in seasonal as well as annual temperature and rainfall. The seasons are projected to be warmer by around 2°C towards 2030s. The variability of seasonal mean temperature may be more in winter months. The increase in mean daily minimum temperatures projected under the A1B scenario is much larger than the change in mean daily maximums. There is a general trend of increase in precipitation for all the case studies.

371. The indications from the PRECIS A1B scenario are that by mid-century, monsoon precipitation could increase by 15-20% in the upper basin. In the lower basin, increases in monsoon precipitation are not as high, but may offset increases in potential evapotranspiration caused by higher temperatures. An impact of increased precipitation could be increased flood frequency and magnitude. Figure 12 shows the PRECIS simulated average number of days with more than 100 mm of precipitation, and Figure 13 the number of days with over 150 mm of rainfall. The average number of days increases, particularly in the foothills of the Himalayas and this could result in increased flood activity both in the Sutlej and on the smaller rivers draining directly onto the plain, such as the Gagar.

Figure 74 Simulated Season and Annual Rainfall and Temperature



Note: For min temp in annual 1970 and JF 2080 values are +0.2°C and +0.1°C respectively

5. Potential Evapotranspiration

372. Potential evapotranspiration has been estimated from PRECIS simulated weather data for three locations in the Sirhind irrigation command in the lower Sutlej basin. These locations were chose to be representative of the southwestern part of the command, the middle and the area close to the Ropar headworks. The computed annual potential evapotranspiration figures are given in Table 46 below.

Table 46 Changes in Annual Potential Evapotranspiration in the Sirhind command

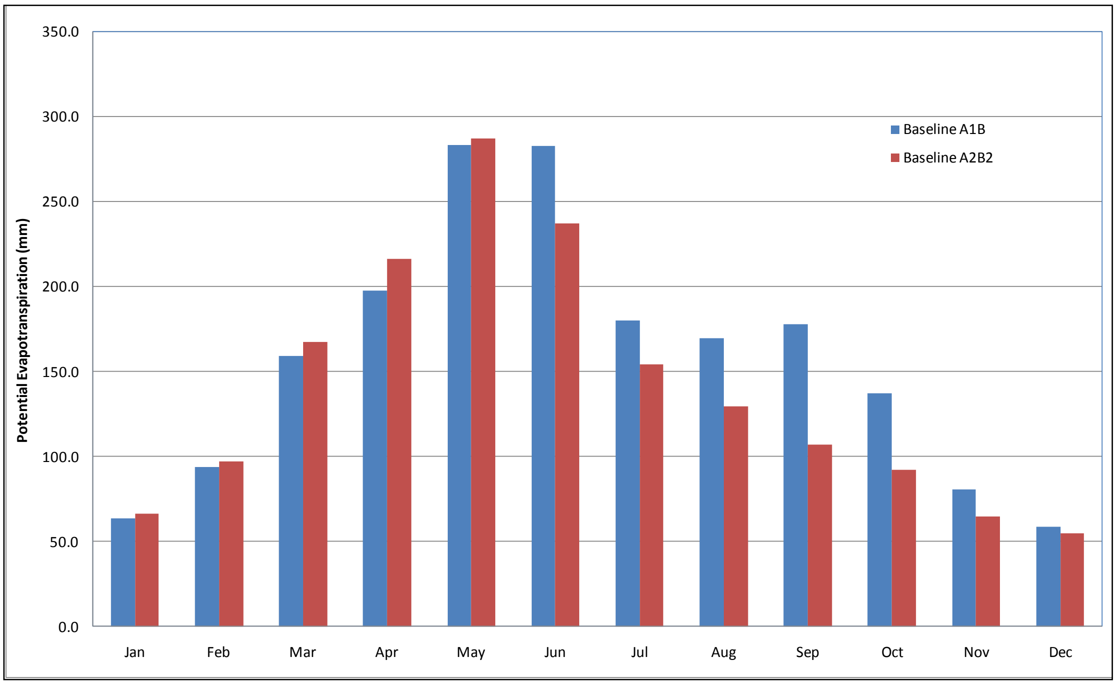
	ETo (mm)		
Location	**Baseline**	**Mid-century**	**End-century**
Southwest	1890	1900	2080
Middle	1680	1660	1810
Ropar Headworks	1260	1290	1350

373. Little change in ETo is forecast by mid-century under the A1B scenario, although by the end of the century there is approximately a 10% increase. The estimates of annual ETo are higher than those made from the CLIMWAT database in the southwest, and lower in the northeast. It has also been noted that there is bias in the seasonal distribution of calculated ETo in the northeast of the irrigation command.

374. The forecast increase in evapotranspiration with the PRECIS A1B scenario are not significant in the short term to medium term, and under this scenario, crop water requirements will not change significantly.

375. A calculation was also carried out of potential evapotranspiration in the southwest of the Sirhind command using the PRECIS A2B2 baseline simulation. This is compared with the A1B baseline in Figure 75. The A2B2 baseline simulates 200 mm less evapotranspiration annually in the baseline. Comparison with calculations based on observed data indicates that PRECIS based calculations over-estimate ETo in the first half of the year and under-estimate in the second half.

Figure 75 Potential Evapotranspiration from PRECIS A1B and A2B2 Scenario Climate Parameters



H. Water Resources

1. Hydrological Simulation Studies

376. Evaluating the potential impacts of climate change on water resources requires the application of hydrological simulation modelling techniques, driven by scenarios of changes in precipitation and potential evapotranspiration derived from global and regional climate modelling studies. As indicated above, precipitation is one of the least well represented processes in climate models at present, and the uncertainty in projections of climate change impacts on water resources is therefore high. Current practice is to try and use a range of different climate models, to create an ensemble of possible futures through which an appreciation of uncertainty can be gained, and the robustness of adaptation responses evaluated. If the near future (2030s) is the main focus, the model projections are largely independent of the emission scenarios, as the changes are mainly due to historical emissions and the slow response of the Earth's climate system. However, inter-model uncertainty should be considered.

377. The SWAT model has been used with climate simulations from the A1B emissions scenario from PRECIS. The model was calibrated using data from the IMD 0.5^{o} precipitation and temperature data (and Aphrodyte data where there was no IMD coverage) and observed flow data from CWC and state gauging stations.

378. In the Sutlej basin the intention had been to use the SWAT model primarily for the catchment upstream of Bhakra reservoir. As will be noted from Figure 69, however, PRECIS precipitation simulation is very poor in the Himalayas.

379. IITM have run the PRECIS model on the A1B emissions scenario with three perturbed model parameter sets that provide for some level of inter-model variability. The full integrations for these PRECIS runs were requested, but only one was made available, and only for baseline , 2021-2050 and 2071-2098. The PRECIS model has also been run with the A2 and B2 scenarios, but only for the time slice 2071-2100.

2. SWAT Model Set Up

380. The SWAT model was set up using the following spatial data:

- Digital Elevation Model: SRTM, of 90 m resolution[49]
- Drainage Network – Hydroshed[50]
- Soil maps and associated soil characteristics (source: FAO Global soil)[51]
- Land use: Global Map of Land Use/Land Cover Areas (GMLULCA), IWMI's Global Map of Irrigated Areas (GMIA) (source: IWMI) [52]

381. The hydro-meteorological data required for the SWAT model include daily rainfall, maximum and minimum temperature, solar radiation, relative humidity and wind speed. These weather data were sourced as follows:

- IMD gridded weather data (1971–2004) – 5 years of weather data was used as warmup/setup period for the Sutlej basin model thus outputs were available from 1976 to 2004
- APHRODITE precipitation data for the upper basin as a substantial part of the basin lies in China
- Climate Change: PRECIS Regional Climate Model outputs for Baseline (1961–1990, BL) , near term (2021-2050, MC) and long term or end-century (2071-2098, EC) for A1B IPCC SRES scenario[53] (Q14 QUMP ensemble)

[49] http://srtm.csi.cgiar.org
[50] http://hydrosheds.cr.usgs.gov/
[51] http://www.lib.berkeley.edu/EART/fao.html
[52] http://www.iwmigiam.org/info/main/index.asp
[53] http://www.tropmet.res.in/static_page.php?page_id=51

382. **Mapping the Sutlej Basin**: The ArcSWAT (Winchell et al., 2007[54]) interface was used to pre-process the spatial data. The DEM for the basin is shown in Figure 76, and Table 11 summarises the key elevation characteristics. Automatic delineation of watersheds uses the DEM as input, with a target outflow point selected interactively. The Sutlej river basin has been delineated using 5,000 ha as minimum stream threshold which resulted in 1092 sub-basins. These sub-basins are shown in Figure 17. Basin area of the Sutlej up to the basin outflow point is 97522 km^2. Care was also taken to incorporate the locations of stream gauge measurement locations while undertaking the delineation process.

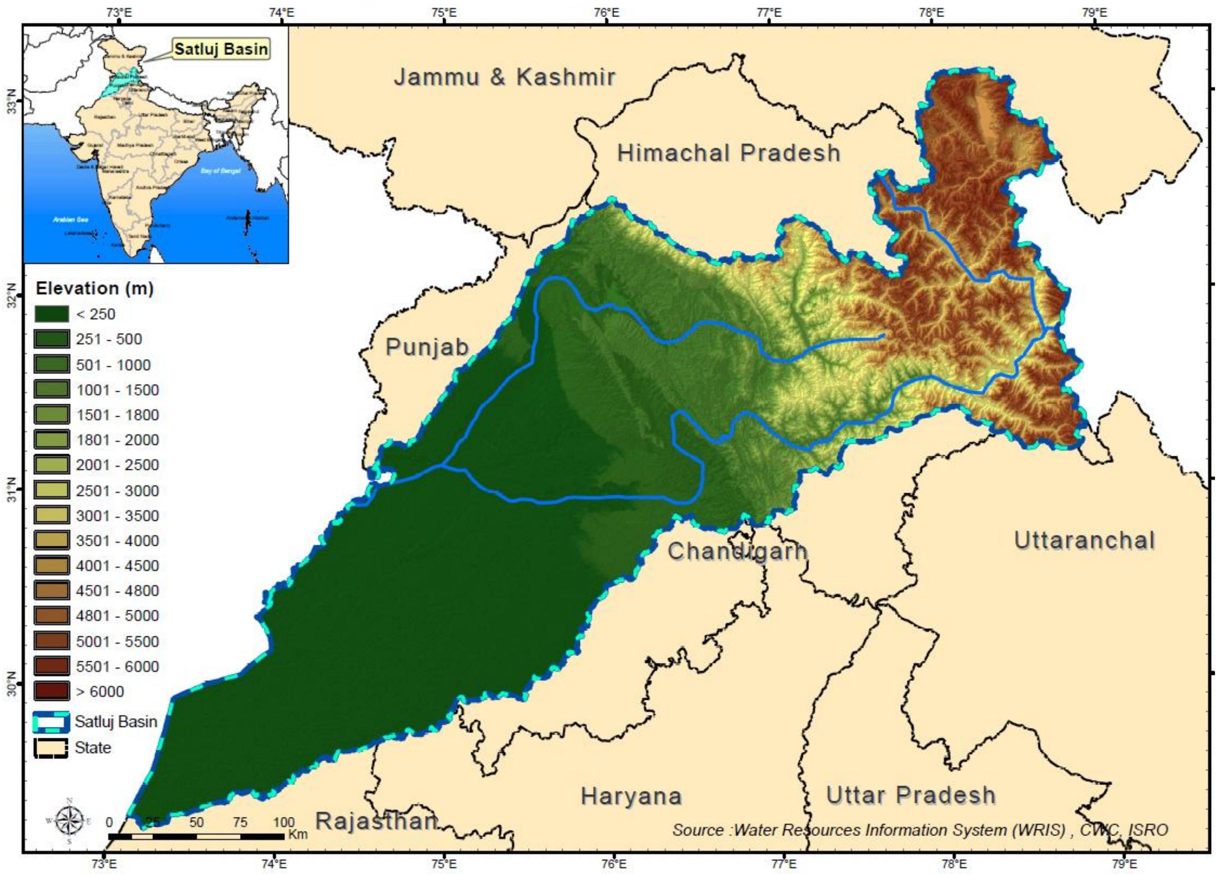
Table 11 Elevation Summary – Sutlej Basin

Parameter	Elevation (masl)
Minimum Elevation	100
Maximum Elevation	6857
Mean Elevation	2870

383. Land Use/Land Cover is another important component of data that is required for pre-processing. The IWMI Global Map of Land Use/Land Cover Areas, as shown in Sub basin delineation is shown in Figure 77 and land use in Figure 78.

384. Figure 76 was used. Table 12 gives the land use categories and the area covered under each category for the Sutlej basin. The major part of the upper basin has grass land and forest and lower basin is under agriculture land use, with rice and wheat as the predominant crops. Sub basin delineation is shown in Figure 77 and land use in Figure 78.

Figure 76 Digital Elevation Model of Sutlej Basin



54 Winchell, M., Srinivasan, R., Di Luzio, M., Arnold, J., 2007. ArcSWAT interface for SWAT2005. User's Guide. BRC, TAES, USDA-ARS, Temple, TX

Figure 77 Sub-basin delineation using DEM

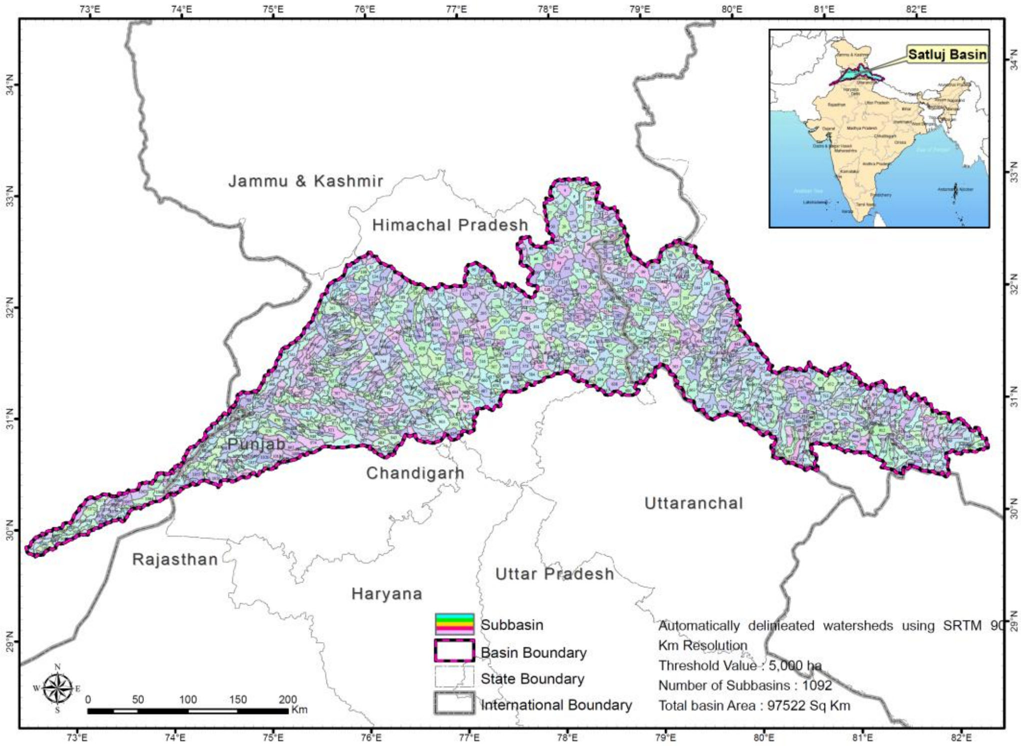


Figure 78 Sutlej Basin – Land use map

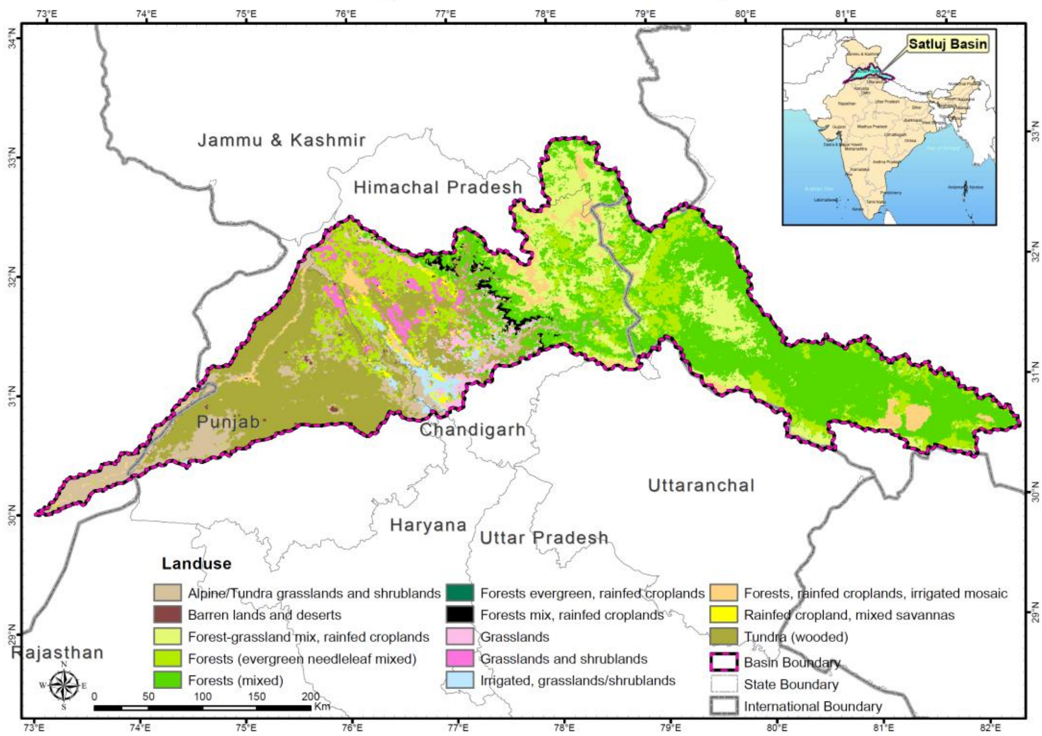
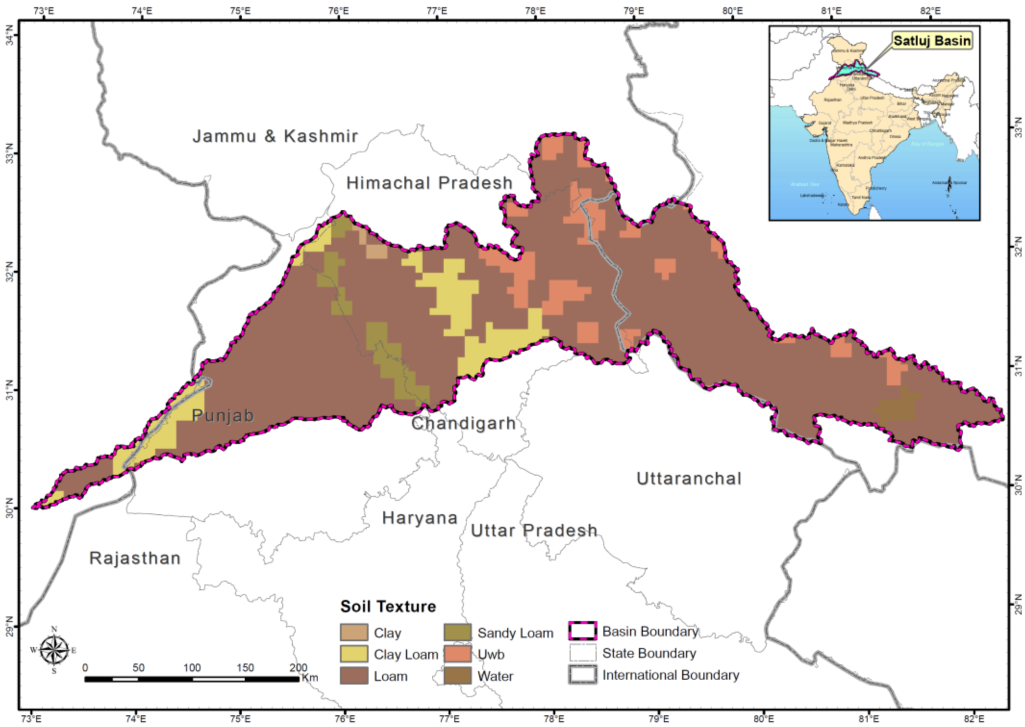


Table 47 Land use Categories

Land Use	Area (ha)	% of Watershed Area
Agriculture	3228781	33
Forest	1481170	15
Range/grassland	4599570	47
Water/Wetland/Misc	442707	5

385. **Soils Data**: Spatial information on soil profiles is required for simulating the hydrological character of the basin. In the absence of high resolution soil data, the FAO global soil map was used for the modelling of the Sutlej basin. The soil is predominantly Loam however; clay loam and sandy loam is also present. The soils map is shown in Figure 79.

Figure 79 Sutlej Basin – Soils map



3. SWAT Model Calibration and Performance

386. **Model Evaluation Statistics (Dimensionless):** Statistical parameters namely regression coefficients (R^2) and Nash-Sutcliffe efficiency (NSE) were used to assess the model efficiency on monthly SWAT hydrologic streamflow predictions. The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (Nash and Sutcliffe, 1970[55]). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as:

$$NSE = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs}-Y^{mean}\right)^2}\right]$$

where Y_i^{obs} is the ith observation for the constituent being evaluated, Y_i^{sim} is the ith simulated value for the constituent being evaluated, Y^{mean} is the mean of observed data for the constituent being evaluated, and n is the total number of observations. NSE ranges between −∞ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance[56].

387. **Coefficient of determination (R^2)**: Coefficient of determination (R^2) describes the degree of co-linearity between simulated and measured data. R^2 describes the proportion of the variance in measured data explained by the model. R^2 ranges from 0 to 1, with higher values indicating less error

[55] Nash, J. E., and J. V. Sutcliffe. 1970. River flow forecasting through conceptual models: Part 1. A discussion of principles. J. Hydrology 10(3): 282-290

[56] Moriasi, D. N., J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, and T. L. Veith, 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, Transactions of the ASABE, Vol. 50(3): 885−900 2007

variance, and typically values greater than 0.5 are considered acceptable (Santhi et al., 2001[57], Van Liew et al., 2003[58]). R2 is oversensitive to high extreme values (outliers) and insensitive to additive and proportional differences between model predictions and measured data (Legates and McCabe, 1999[59]).

388. **Model validation** has been made using the observed data for the period 1976-2004 at a monthly time step. For this purpose data from four stream flow monitoring stations upstream of Bhakra dam (Figure 80) were used. Stations used were Rampur, Suni, Kasol and Bhakra. Before performing a statistical comparison of streamflows, the reasonableness of the model for general evapotranspiration, runoff, base flow/return flow, and crop yields against district averages were analyzed and found satisfactory. The SWAT model results and time series plots are presented in Table 48 and Figure 81 to Figure 84 respectively for each stream flow station. The long-term simulated monthly means at all drainage area levels are on par with observed means, the R^2 and coefficient of efficiency are above literature acceptable ranges from 0.78 to 0.87 and 0.42 to 0.67 respectively. Given the data availability, particularly in the upper basin, the calibration/validation results are satisfactory.

Figure 80 Sutlej Basin –Stream gauge locations

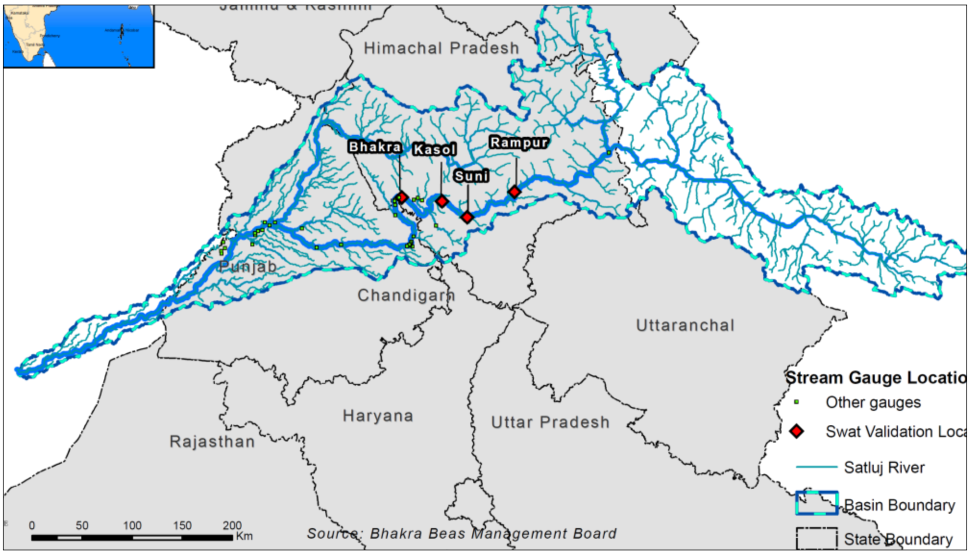


Table 48 SWAT model efficiency parameters for the Sutlej Basin

Gauge Site	Catchment Area*(km^2)	Mean Flow*(m^3/s)	Start Year	End Year	COE**	Correlation coefficient
Rampur	50000 (49550)	345 (390)	1963	2005	0.42	0.83
Suni	NA (51660)	427 (379)	1969	2005	0.52	0.78
Kasol	NA (52350)	417 (414)	1985	2005	0.62	0.84
Bhakra	56000 (55310)	458 (427)	1963	2005	0.67	0.87

Note: * Model parameter is shown in bracket, ** Nash-Sutcliffe coefficient

[57] Santhi, C, J. G. Arnold, J. R. Williams, W. A. Dugas, R. Srinivasan, and L. M. Hauck. 2001. Validation of the SWAT model on a large river basin with point and nonpoint sources. J. American Water Resources Assoc. 37(5): 1169-1188

[58] Van Liew, M. W., J. G. Arnold, and J. D. Garbrecht. 2003. Hydrologic simulation on agricultural watersheds: Choosing between two models. Trans. ASAE 46(6): 1539-1551

[59] Legates, D. R., and G. J. McCabe. 1999. Evaluating the use of “goodness-of-fit” measures in hydrologic and hydroclimatic model validation. Water Resources Res. 35(1): 233-241

Figure 81 Sutlej Basin –Calibration at Rampur

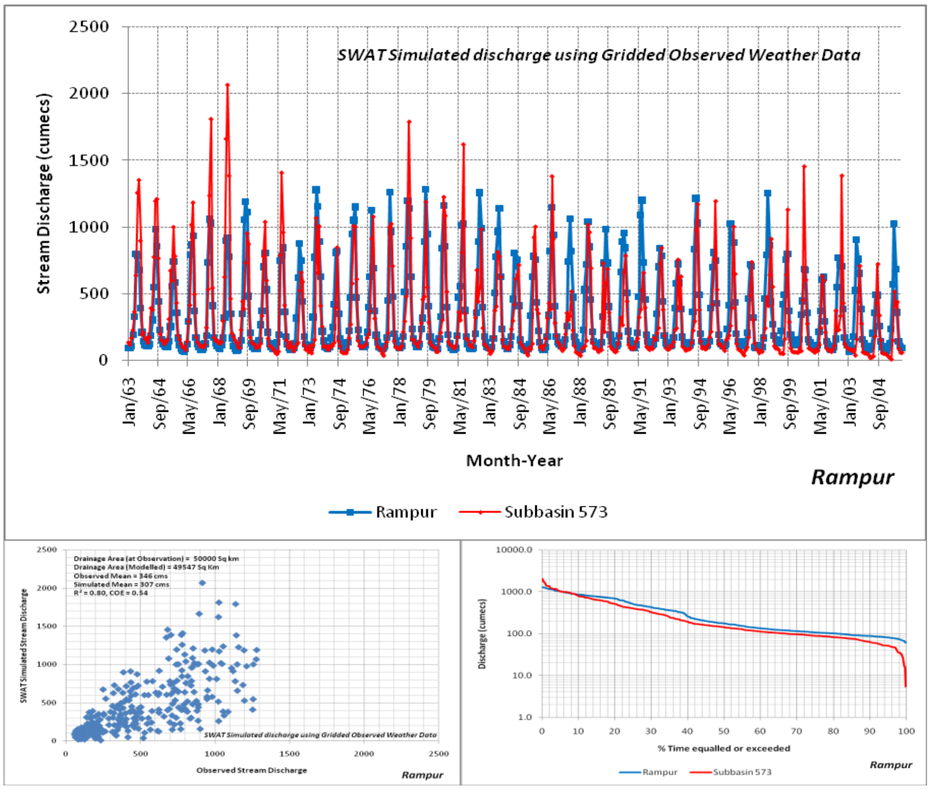


Figure 82 Sutlej Basin –Calibration at Suni

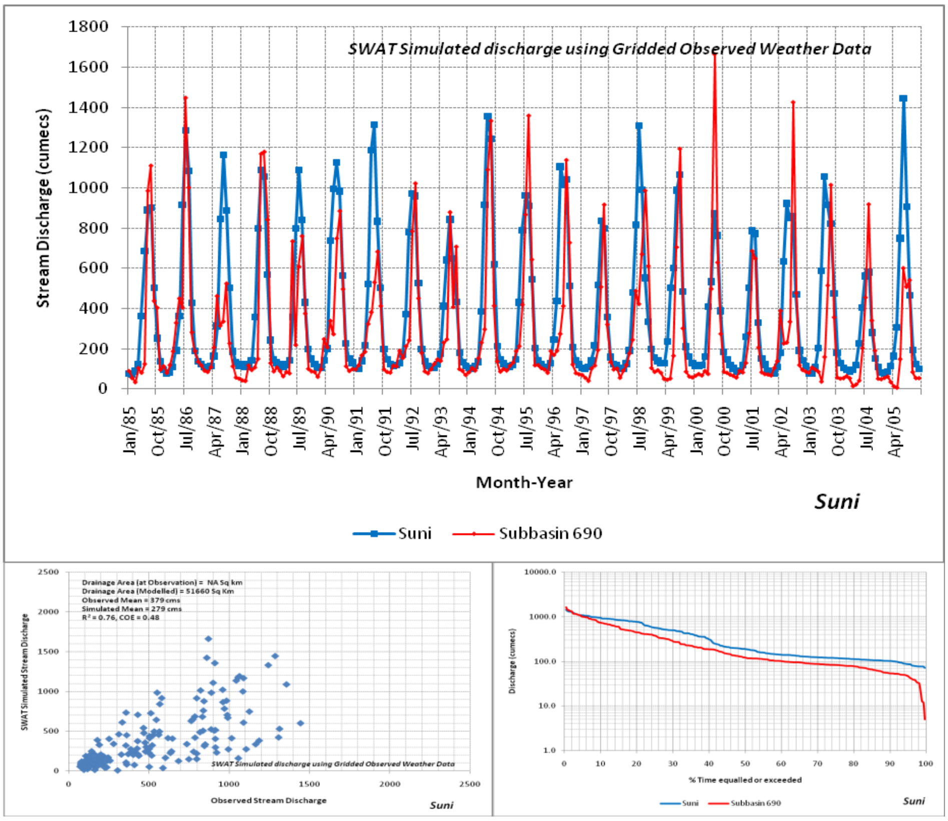


Figure 83 Sutlej Basin –Calibration at Kasol

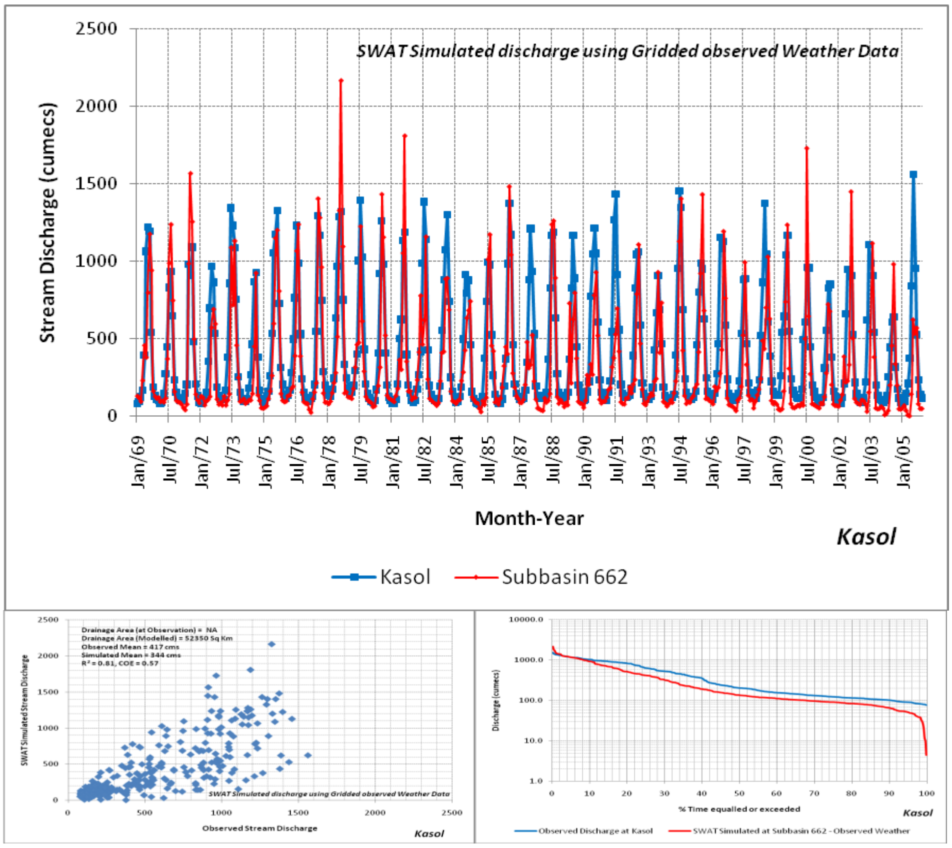
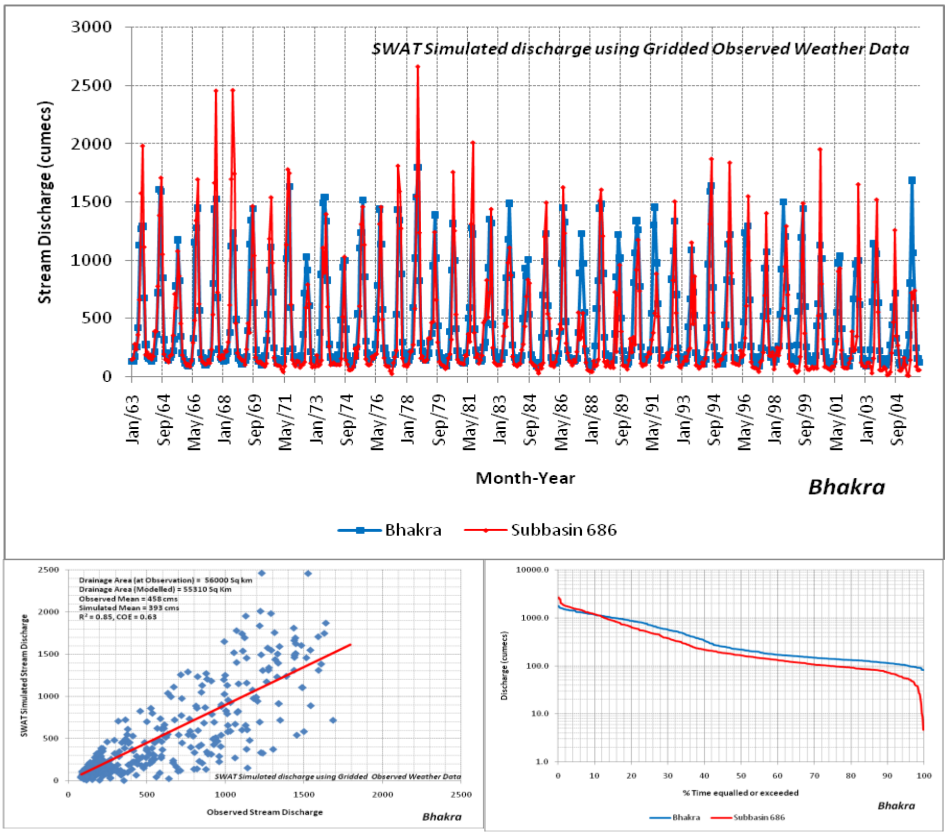


Figure 84 Sutlej Basin –Calibration at Bhakra



4. Modelling Climate Change Impacts on Hydrological Response

389. **Model Outputs** are very extensive, covering all the components of water balance spatially and temporally. The sub components of the water balance that are most significant and used for analyses, include:

- Precipitation
- Total flow (Water yield) consisting of surface runoff, lateral and base flow
- Actual evapotranspiration (Actual ET)

390. **Mean annual and seasonal precipitation** on the basin are shown in Figure 85. Inter-annual variability in annual and seasonal precipitation is shown in Figure 86. The highest precipitation occurs in the foothills of the Himalayas, with most precipitation occurring during the southwest monsoon. There is clearly significant spatial and temporal variability in precipitation, and this has a significant influence on hydrological response in different parts of the basin.

Figure 85 Sutlej Basin – Annual, JJAS and OND precipitation

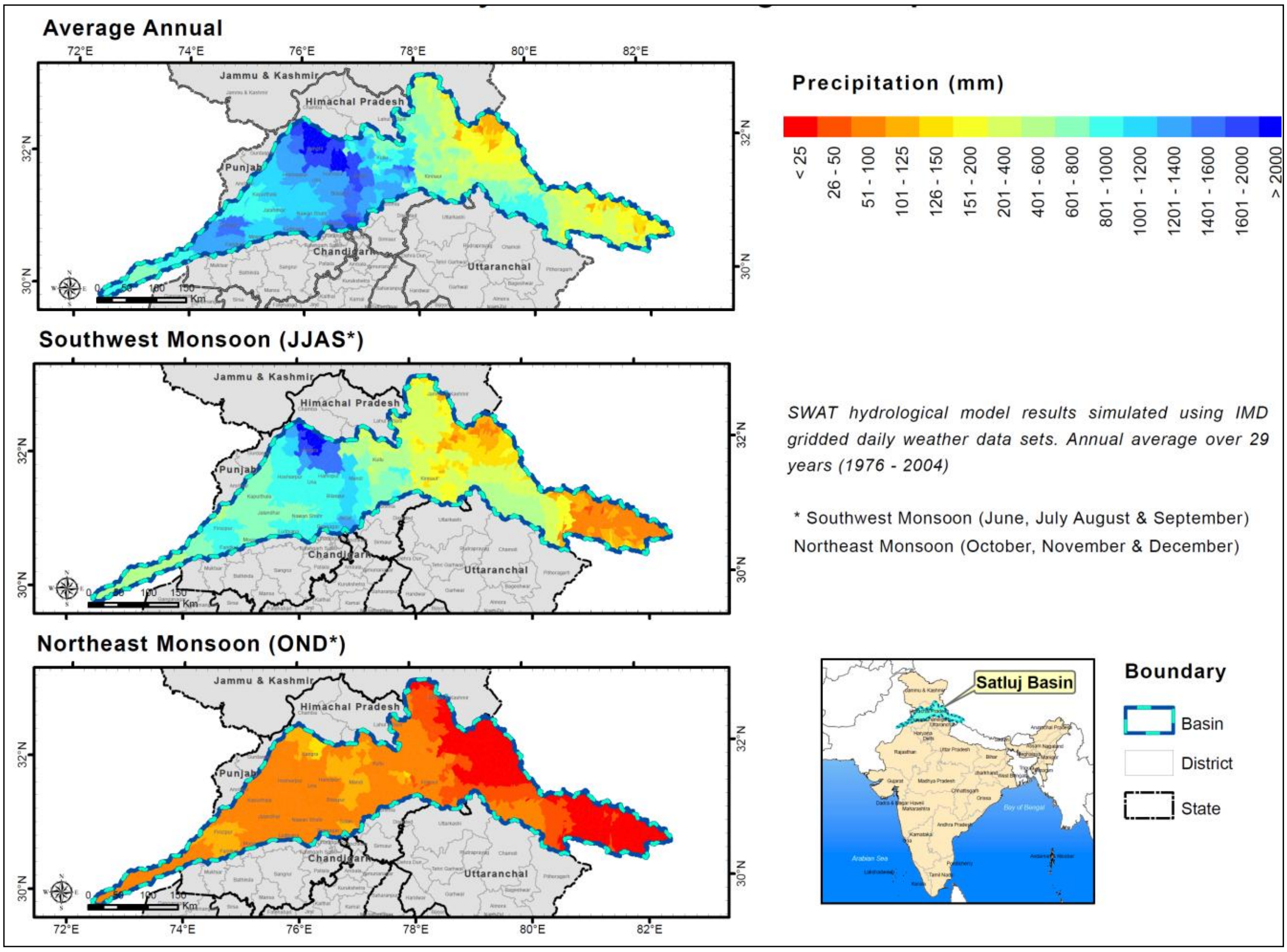
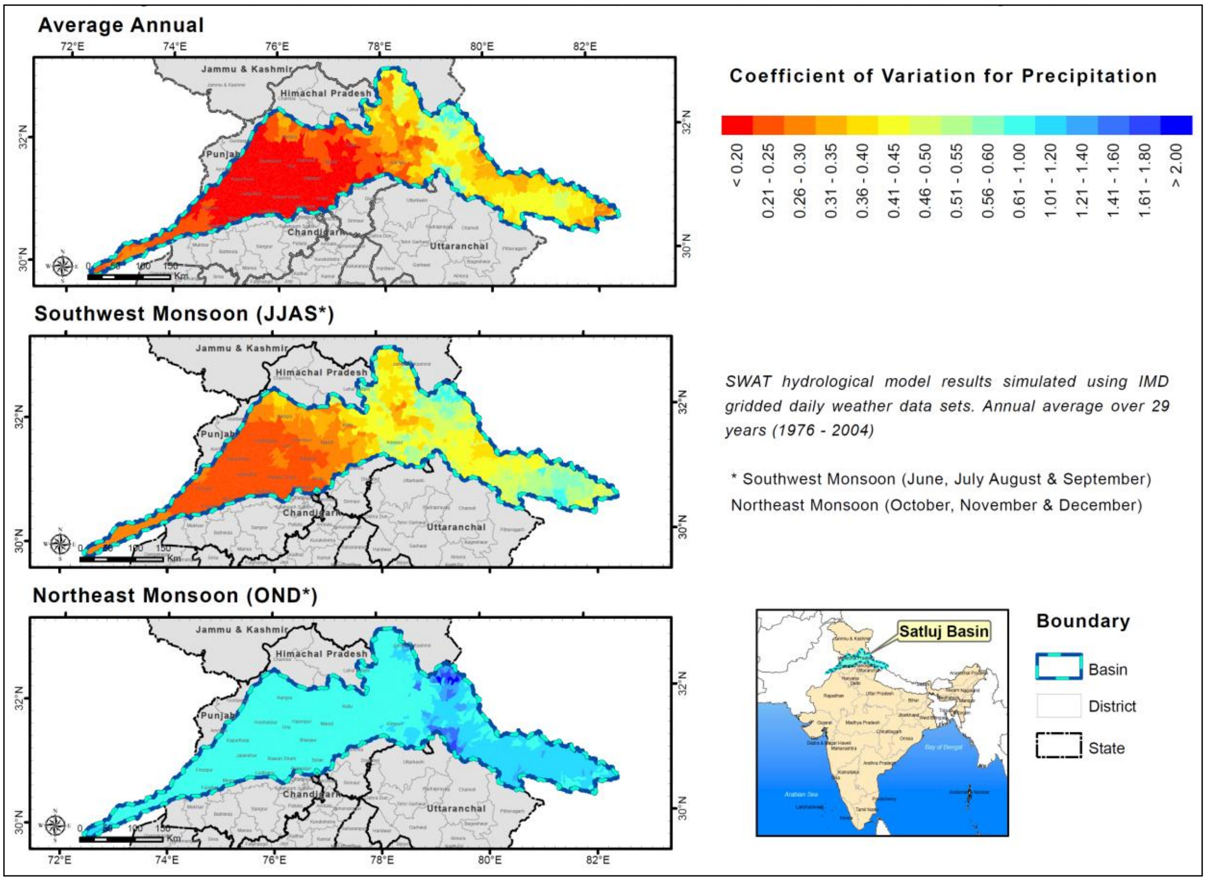


Figure 86 Sutlej Basin – Variability in Annual, JJAS and OND Precipitation



391. **Baseline PRECIS simulation, upper basin**: Prior to attempting to assess the potential impacts of the A1B climate change scenario on runoff response in the upper basin, an evaluation was made of how well the statistics of observed streamflow could be matched with the statistics of streamflow simulated by SWAT using PRECIS simulated baseline weather data. It was found that with PRECIS simulated weather data, river flows were over-simulated by almost an order of magnitude.

392. **Precipitation** simulated by PRECIS in parts of the upper basin was more than three times higher than the estimated observed precipitation, while potential evapotranspiration calculated from PRECIS simulated data was significantly lower. It is concluded that at this time, the PRECIS model is not capable of adequately simulating climatic conditions in the Himalayan region. The simulated baseline climate is at present so significantly different from that observed, that no meaningful bias adjustment of PRECIS results is possible. It is considered that the results are so different from observations, that there could be little confidence even in simulated changes in climate under future emissions scenarios. Assessment of possible climate change impacts on river flows in the upper Sutlej using PRECIS results to drive the SWAT model is not at this time possible.

393. **Satisfactory modelling** of the existing climatic conditions in the Himalayas will require improved GCMs providing boundary conditions for RCMs running at a much higher resolution than has been possible thus far. In view of the importance of the water resources of the region this should clearly be a priority research area.

394. **Lower basin simulation**: Although PRECIS weather simulations in the upper basin were not considered to be suitable for hydrological modelling, the PRECIS simulation of baseline climatic conditions in the lower basin was considered to be satisfactory. The SWAT model was used in the lower basin to assess possible changes in water balance components under the influence of climate change.

395. **Simulated climate outputs** from PRECIS regional climate model for present (1961–1990, BL) near term (2021-2050, MC) and long term (2071-2098, EC) for the A1B SRES were used. One realisation of the HADCM3 QUMP (Quantifying Uncertainty in Model Predictions, Q14) provided the boundary conditions for the PRECIS run.

396. The SWAT model was used to determine the present water availability in space and time without incorporating any man made interventions such as dams, diversions, etc. The same framework was then used to simulate the impact of the climate change scenario on the water resources with the assumption that the land use does not change over time. A total of 90 years of simulation have been conducted: 30 years belonging to IPCC SRES A1B baseline (BL), 30 years belong to IPCC SRES A1B near term or mid-century (MC) climate scenario and 30 years belong to IPCC SRES A1B long term or end-century (EC) climate scenario.

397. Projected changes in precipitation in the Sutlej catchment have been discussed as part of the climatic assessment reported in Section III of this report. The detailed outputs of the SWAT hydrological model were analysed for the lower basin with respect to the two major water balance components of water yield and actual evapotranspiration. These are significantly influenced by the intensity and temporal distribution of precipitation, and by the weather conditions dictated by temperature and allied parameters.

398. **Analysis of Change in Water balance components**: The outputs of the near term and long term scenarios have been analyzed with respect to the baseline considering possible impacts on the runoff, baseflow, actual evapotranspiration and ground water recharge. Table 49 gives the summary of changes in water balance components as percentage distribution of the change in precipitation from baseline to mid century.

Table 49 Summary of Change in Water Balance Expressed as Percent Change in Precipitation

Scenario/Season	Precipitation	Evapotranspiration	Surface Runoff	Baseflow+	Total Water Yield*	Ground Recharge**
Avg Annual (A1B-Baseline)	402	290	71	0	73	52
Avg Annual (A1B-Mid Century)	512	327	125	1	127	73
Percent Change in precipitation	27					
Net change (mm)	110	37	54	0	54	21
Change (%)***		34	49	0	49	19
Avg JJAS (A1B-Baseline)	316	127	65	0	65	42
Avg JJAS (A1B-Mid Century)	411	135	114	0	115	56
Percent Change in precipitation	30					
Net change (mm)	95	8	49	0	49	14
Change (%)***		8	52	0	52	15
Avg OND (A1B-Baseline)	37	36	4	0	4	5
Avg OND (A1B-Mid Century)	53	39	8	0	9	10
Percent Change in precipitation	41					
Net change (mm)	15	4	4	0	5	5
Change (%)***		23	29	1	31	33

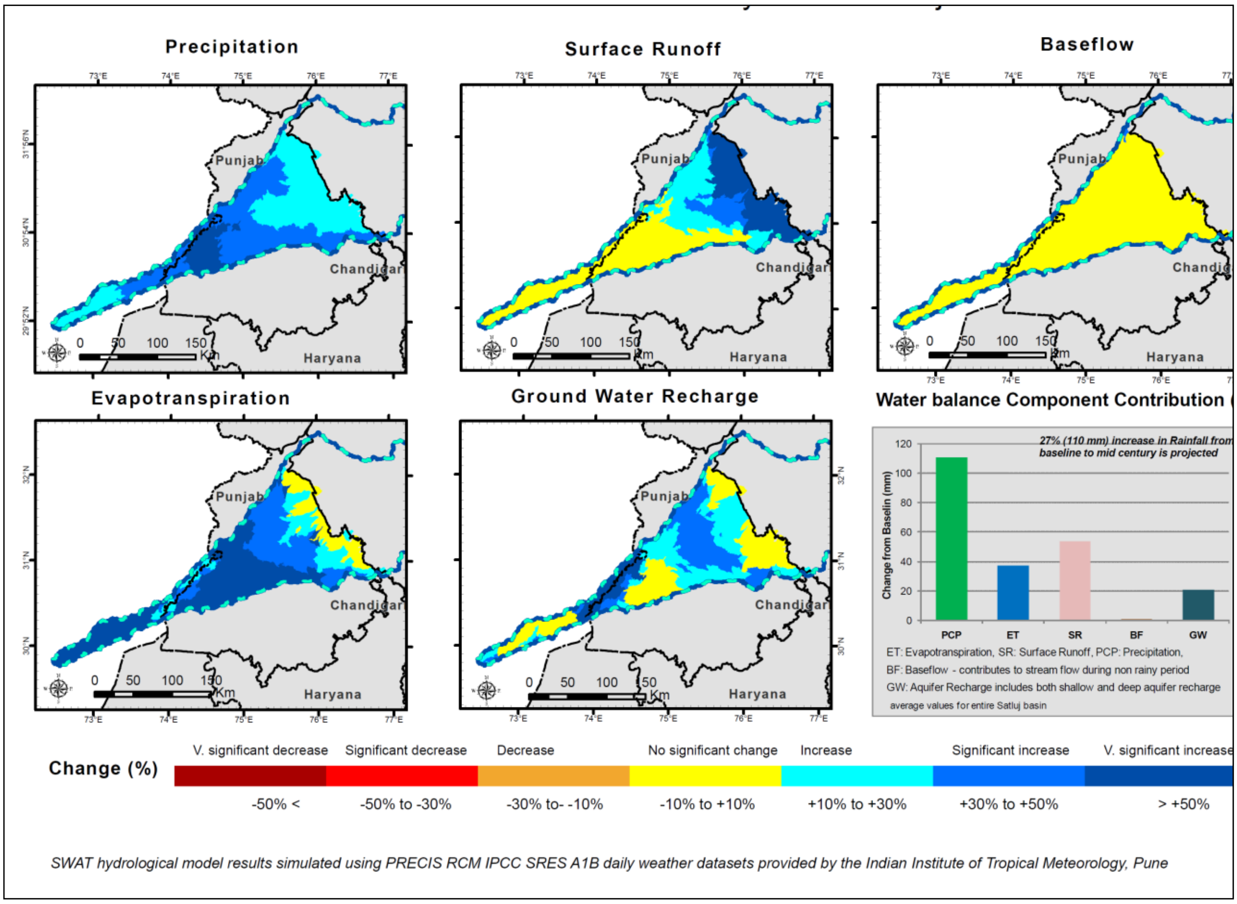
+: Baseflow: contributes to stream flow during non rainy period
* Water Yield (streamflow): surface runoff+baseflow+lateral flow
** Groundwater Recharge: shallow and deep aquifer recharge
***Distribution of water balance components as percentage of change in precipitation

++ All units are in millimetres

399. The PRECIS A1B scenario indicates an increase in annual precipitation in the lower Sutlej basin of about 27% by mid-century. The model results indicate that around 49% of this increase in precipitation will get converted to runoff but with no change in baseflow which contributes to stream flow during lean periods. Aquifer recharge is projected to increased by 19% and evapotranspiration by 34% by mid-century.

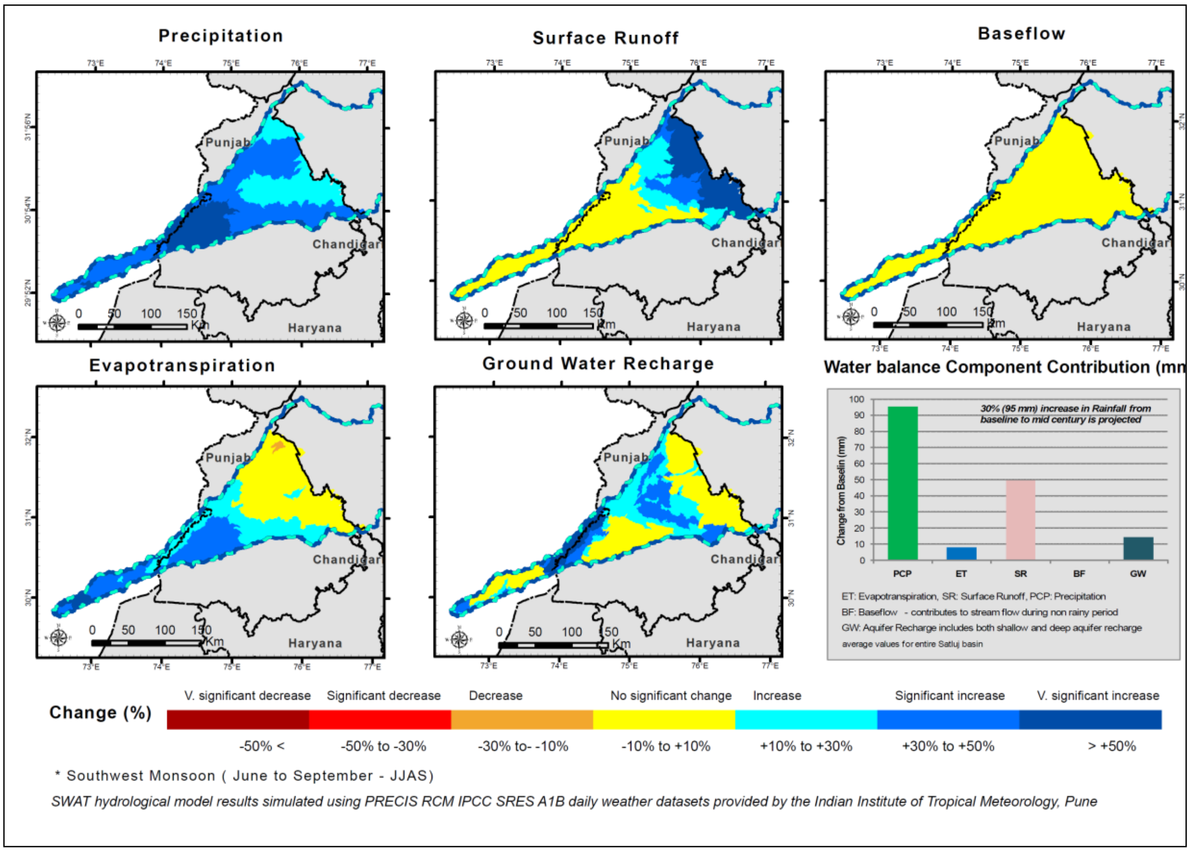
400. Figure 87 also shows the distribution of the major water balance components as percentage change in response to the increase in precipitation. The figure also shows the water balance component averaged over the entire basin and expressed in depth units (mm).

Figure 87 Change in Annual Surface runoff, ground water flow and evapotranspiration from baseline to Mid Century



401. Precipitation changes vary locally in magnitude, sign, and seasonal details for the Sutlej basin. Seasonal changes in precipitation and the SWAT simulated effect on water balance components for JJAS (south west monsoon) and OND (north east monsoon) are included in Table 49. Results for JJAS are shown graphically in Figure 88. Under the A1B scenario, there is increase in JJAS precipitation in the lower Sutlej basin of about 30% by mid-century. The model results indicate that around 52% of this increase in precipitation will get converted to runoff with negligible change in baseflow. An increase in aquifer recharge of 15% is projected, and evapotranspiration is projected to increased by 8%. From Figure 88 it can be seen that there is negligible change in simulated baseflow, and hence most of the increased precipitation has to form surface runoff and groundwater recharge. The indication is that in parts of the basin surface runoff would double under the A1B scenario. This should be treated as a very optimistic projection from a water resources perspective, but would offer opportunities for increased water harvesting and groundwater recharge. A concern should be the potential impact on drainage and on flood risk. Clearly this should be investigated further, and drainage design criteria reviewed. The bar chart depicts the water balance components averaged over the entire lower basin expressed in depth form (mm).

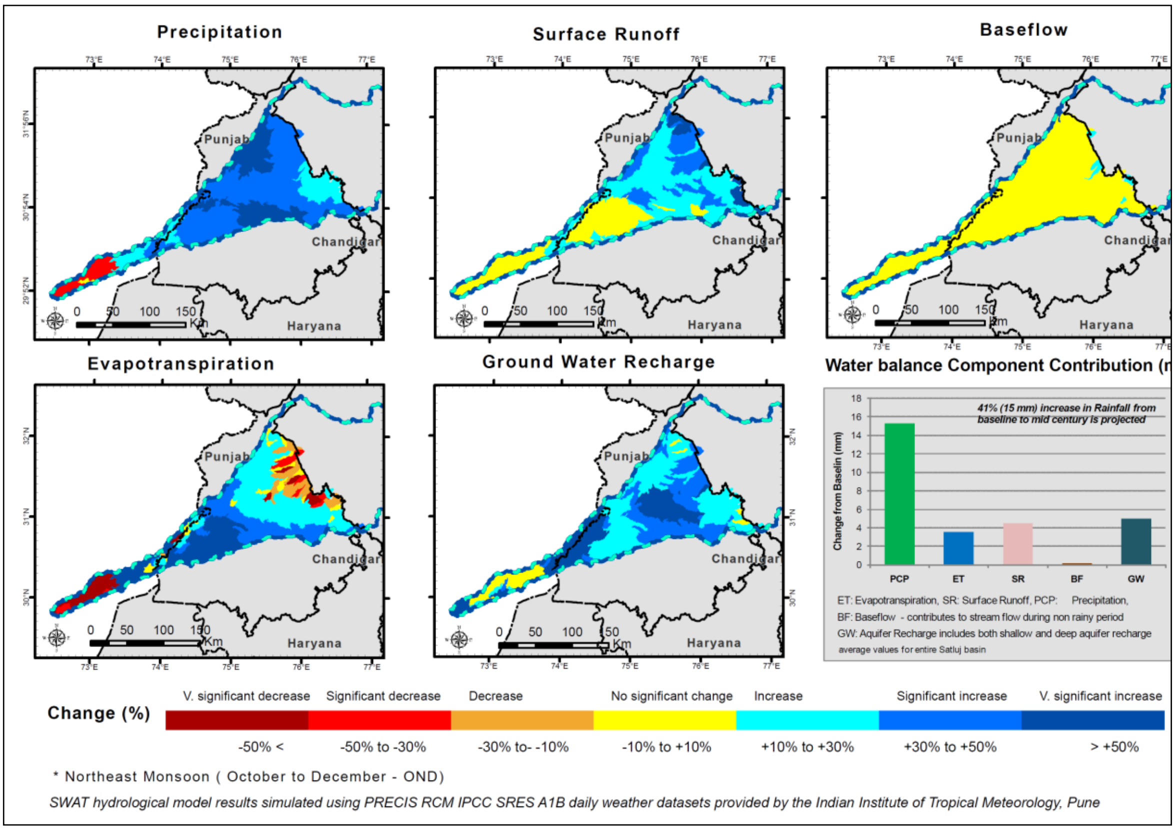
Figure 88 Change in JJAS Surface runoff, ground water flow and Evapotranspiration from baseline to Mid Century



402. During the Rabi season (OND), precipitation is projected to increase by 41% (15mm) resulting in an increase in runoff of 29% and a 33% increase in ground water recharge. Evapotranspiration is projected to increase by 23%, and marginal changes in the baseflow is projected. The contribution of the OND season to the annual water balance is small. Figure 89 presents these changes in water balance components graphically.

403. To conclude, an annual average increase in surface runoff is projected because of climate change, with the largest increase occurring in the southwest monsoon period (JJAS). The disproportionate change in average annual runoff in comparison with change in annual precipitation, can be attributed to more precipitation falling on saturated soils. Increases in evapotranspiration are more significant during northeast monsoon period (OND) which may be attributed largely to increases in temperature.

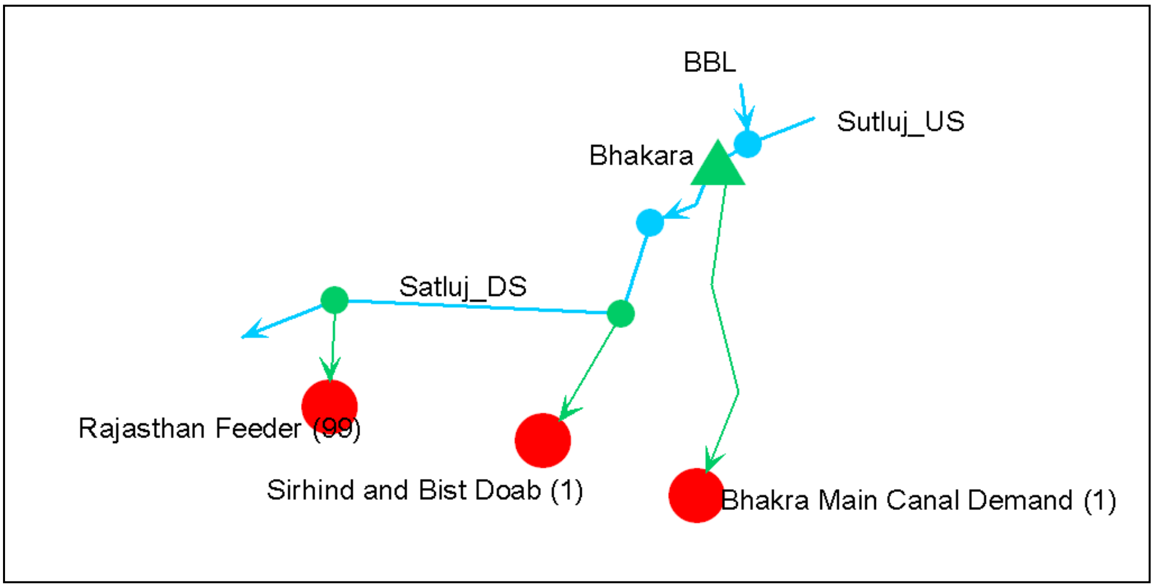
Figure 89 Change in OND Surface runoff, ground water flow and Evapotranspiration from baseline to Mid Century



I. Assessment of Bhakra Reservoir Sensitivity to Changes in Inflows

404. **Reservoir Simulation Modelling**: A very simple reservoir operation model was set up using the WEAP model (Water Evaluation and Planning Model, see www.weap21.org) developed by the Stockholm Environment Institute (SEI). The intention in setting up the model was to gain some understanding of the sensitivity of reservoir yields and hydropower production to changes in inflows to the reservoir that might result from climate change, and through loss of reservoir storage as a result of sedimentation. The schematic for the WEAP model is shown in Figure 90.

Figure 90 Schematic of the Bhakra system



405. Reservoir inflows: Historic inflow data from the upper Sutlej river were available for the period 1963 to 2005. Historic time series diversion data could not be obtained for the Beas-Sutlej Link (BSL), although annual data with Punjab WRD indicated an average annual diversion of 4421 Mm3 during the period 1978 to 2008, with low inter-annual variability. The capacity of the BSL is 564 m3/s, and storage at the diversion point is relatively small at 18.56 Mm3. In the absence of time series diversion data, it was assumed that the BSL functions as a run of river diversion, and that the seasonal distribution of flows would follow that of Sutlej. A synthetic series of BSL diversions was created assuming that the annual diversion was 4421 Mm3, with flows distributed to 10-day periods in the same percentages as in the mean 10-day inflows to Bhakra from the Sutlej. The synthetic BSL record was created for the period 1963 to 2005, and reservoir simulations carried out assuming that the BSL was in place throughout the historic period. The resulting mean annual inflow to Bhakra reservoir was 19,030 Mm3. Figure 91 shows the mean 10-day inflows to Bhakra, including the BSL contribution. The Inter-annual variability in Inflows is not high with a coefficient of variation of 0.12. The annual inflows plotted in normal probability space are shown in Figure 92

406. **Storage at Bhakra**: The current gross storage of Bhakra reservoir at normal top operating level is 8519.3 Mm^3. BBMB completed a reservoir survey in June 2008, from which they concluded that about 25% of reservoir live storage capacity would be lost in about 150 years. To mid-century it would be reasonable to assume a 10% loss in live storage. It would appear that loss of storage is not a significant problem, and in fact the situation will be improved with the construction of further upstream reservoirs. The elevation storage characteristics presented in a BBMB 2008 reservoir survey report were incorporated into the WEAP model.

407. **Operational Rules for Bhakra**: Rule curves for the operation of Bhakra reservoir could not be obtained from BBMB. An analysis was therefore made of historic reservoir levels in order to determine an approximate rule curve and buffer storage limits. Figure 93 shows observed water levels in the period 1990 to 2010. A rule curve for upper conservation storage was taken as the upper envelope of historic water levels. The top of the buffer was taken from the lower envelope of observed water levels as shown in Figure 93.

Figure 91 Mean 10-day inflows to Bhakra Reservoir

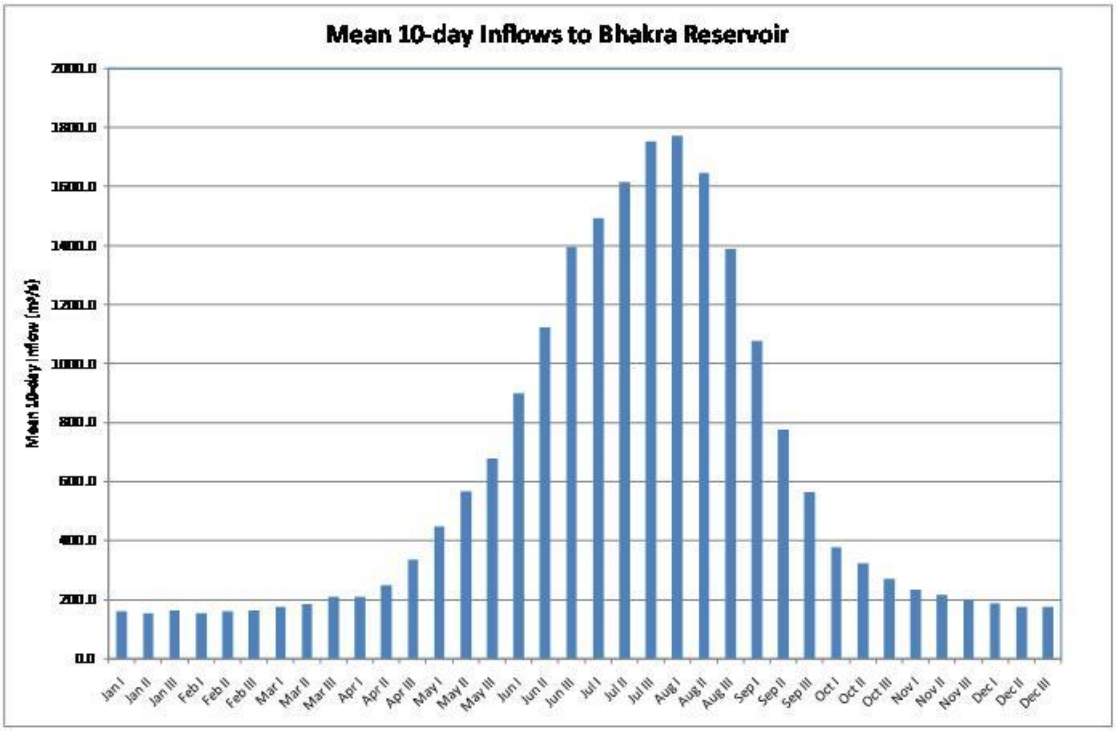


Figure 92 Distribution of annual inflows to Bhakra Reservoir

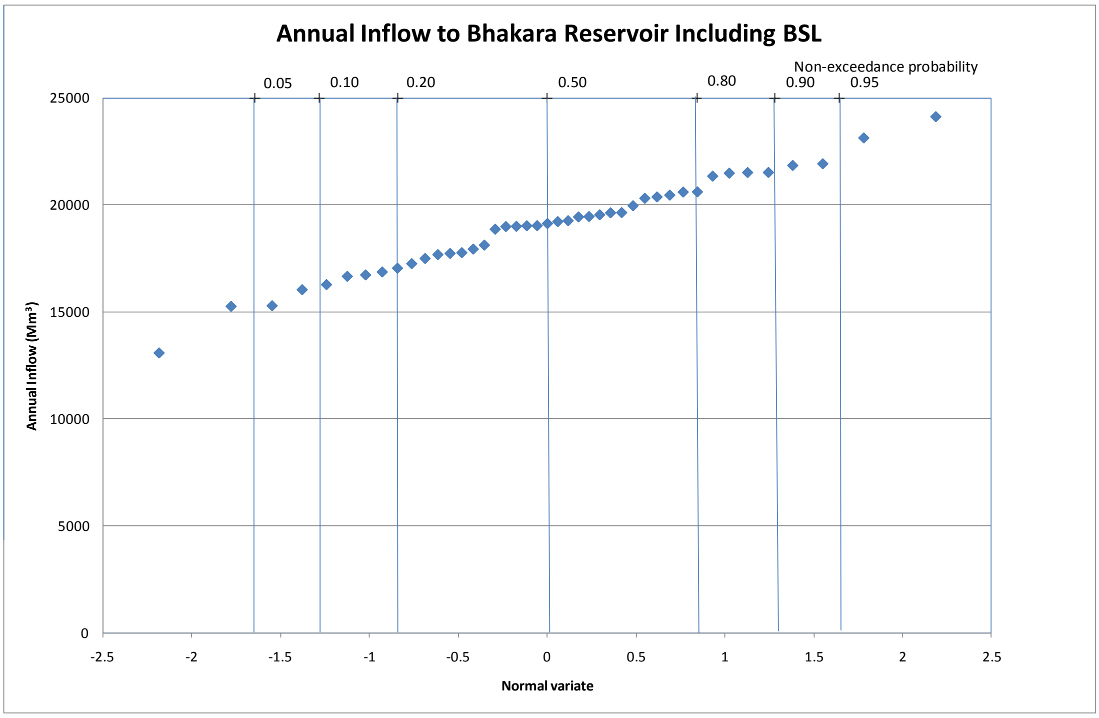
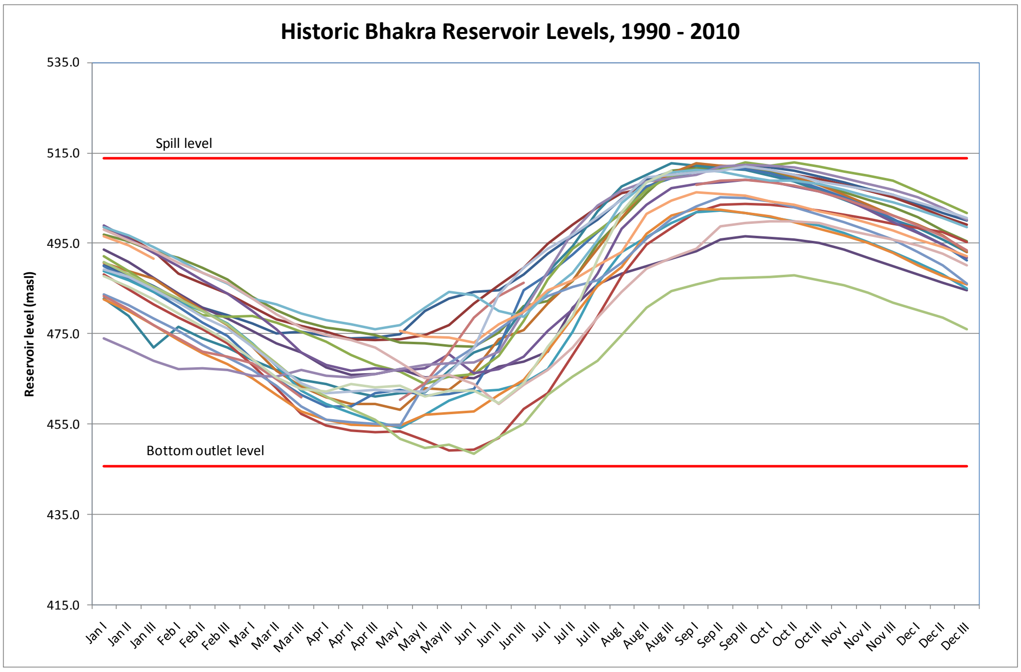


Figure 93 Bhakra Reservoir Levels



408. **Water demands**: A simplified approach to demand estimation was adopted, based on historic diversions to the Bakhra Main Canal, and to the Sirhind and Bist Doab irrigation commands. Historic 10-day flows in the Nangal channel are shown in Figure 94. It will be noted that there is not a significant difference between the average release, and the release in a 10% dry year. The demands for the Bhakra main canal were taken as the average recorded 10-day discharges in the Nangal channel. Figure 95 shows flows in the Sutlej River at Ropar barrage, and diversions to the Sirhind and Bis Doab commands. The average diversions at Ropar were taken as the demands for the Sirhind and Bis Doab areas. The demands of the Rajasthan Feeder on Sutlej water could not easily be determined, and for the purposes of this study were assumed to be 50% of the historic residual flow downstream of Ropar barrage. As neither demands or allocation policies could be properly established, for modelling purposes the Bhakra Main Canal and Sirhind and Bis Doab demands were

given top supply priority and Rajasthan Feeder lowest priority. This simplified yield assessment needs to be verified.

Figure 94 Mean 10-day Flows in the Nangal channel

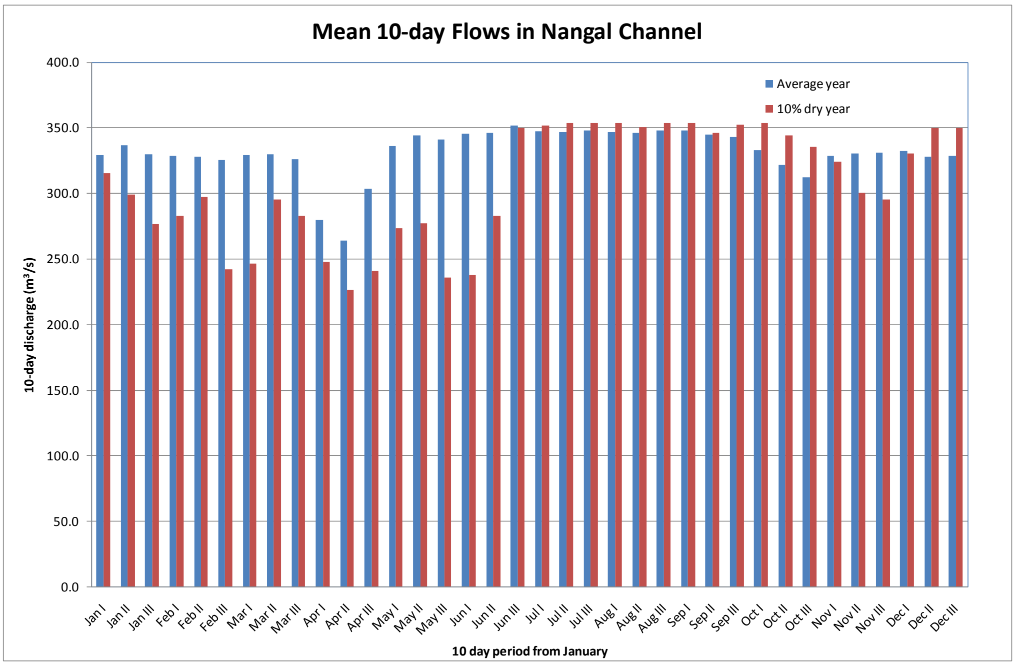
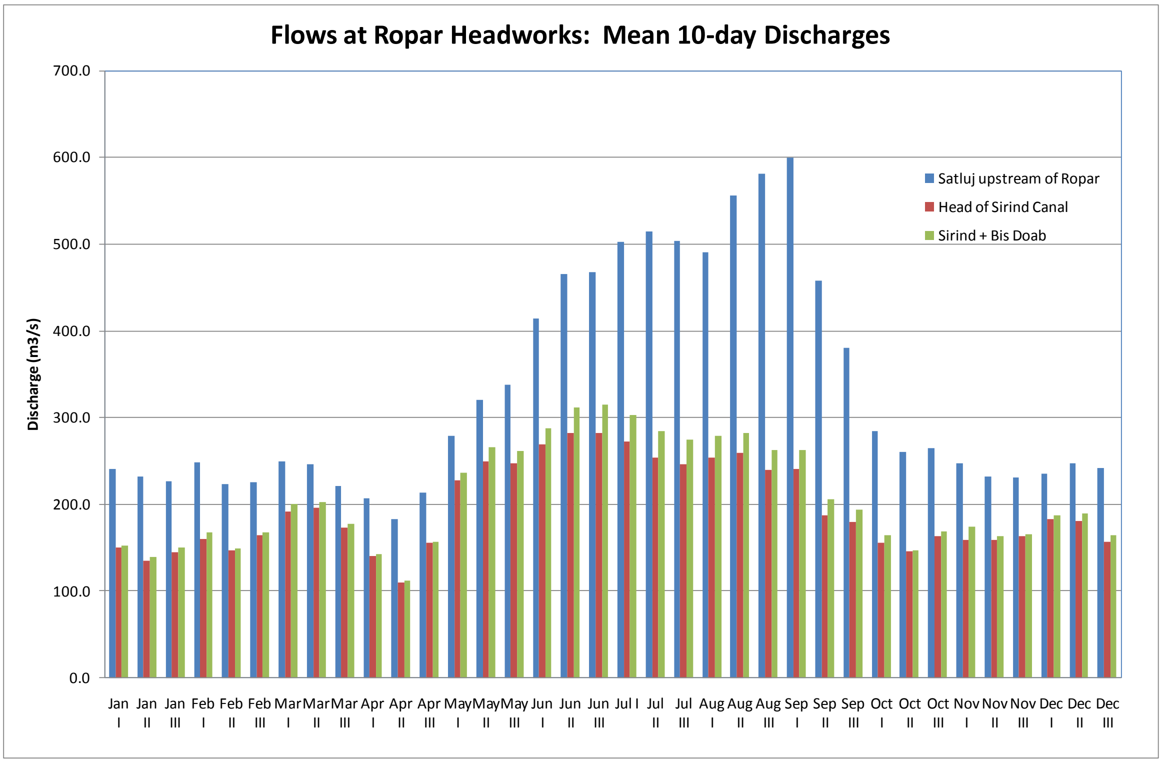


Figure 95 Mean 10-day flows at Ropar Barrage



409. **Hydropower generation**: Bhakra Dam has an installed hydropower capacity of 1.1 GW. The Nangal Dam which acts as an after-bay for re-regulation of peak releases from Bhakra has an installed capacity of 154 MW. Nangal was not included in the WEAP model, and hydropower was computed only for Bhakra. The tailrace elevation was taken to be 356.08 m, and the maximum turbine

discharge to be 850 m^3/s (data could not be obtained, and this figure has been calculated on the basis of installed capacity and maximum operating head). A generating efficiency of 80% was assumed.

410. **Reservoir yields**: The WEAP model was used to explore the sensitivity of reservoir yields, or supply delivered, to changes in inflows and changes in reservoir storage. Four scenarios were run:

- Reference - using the historic inflow series (assuming BSL in place);
- Inflows decreased by 10%;
- Reservoir storage decreased by 10%;
- Reservoir inflows increased by 10%.

411. In each scenario the same demands and reservoir rule curves were used. The results are shown in Figure 96 in terms of supplies delivered at 95% reliability (note that Figure 96 does not present homogeneous sequences). A reduction in inflows by 10% has a significant impact on supply delivery at 95% reliability in February, March and April, but there is little impact in the rest of the year. Reducing live storage by 10% influences supply delivered in April, but again has little impact on the rest of the year. If inflows increased by 10% there would be an improvement in supply reliability, and it would be possible to increase supplies, this has not been tested. Bhakra provides potable water supply as well as irrigation water supply, reliability criteria for potable supply would typically require no restrictions to supply in 98% of years. For irrigation supply, an 80% reliability criteria is common. Supplies delivered at 80% reliability are shown in Figure 96. At 80% reliability there is little impact from any of the scenarios considered. From the results presented here, it would appear that the Bhakra system is quite robust, and that in the short term no significant changes in yield reliability would be expected.

412. **Hydropower production**: Simulated annual hydropower production for each of the four scenarios modelled is shown in Figure 97. Hydropower production is clearly more sensitive to changes in inflows than is reliable yield. Annual hydropower production is not particularly sensitive to loss of reservoir storage, although the reliability with which power can be produced clearly will be affected.

Figure 96 Simulated Bhakra Supply at 80% Reliability

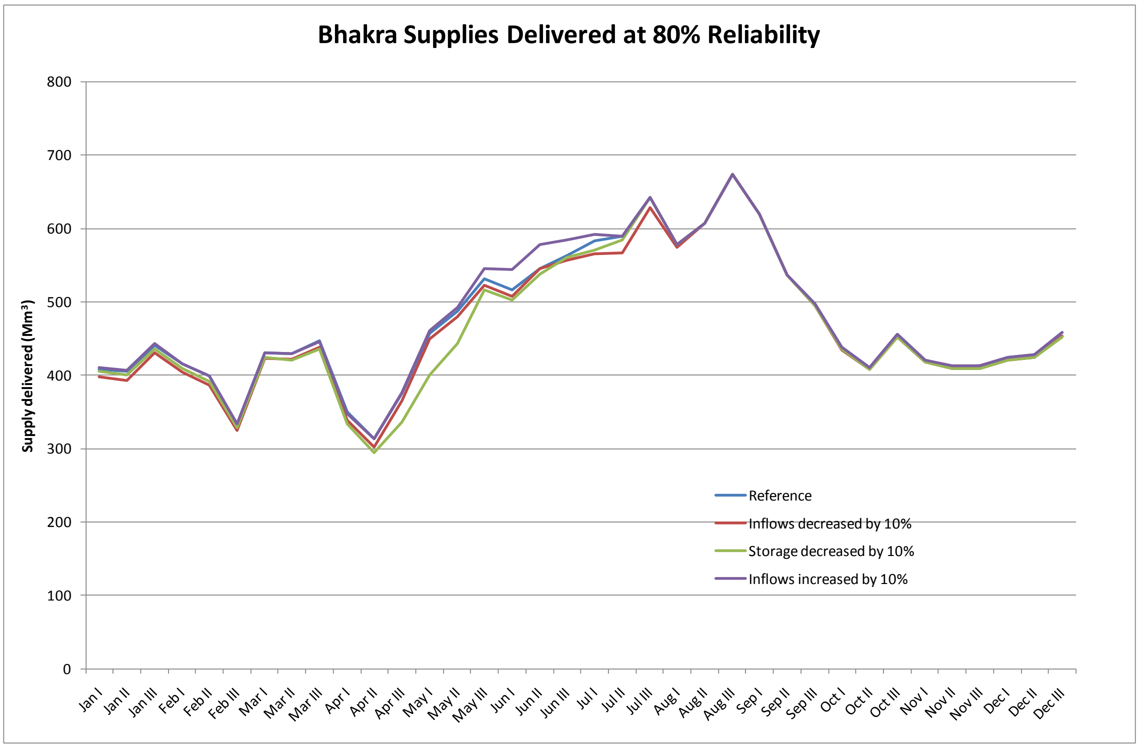
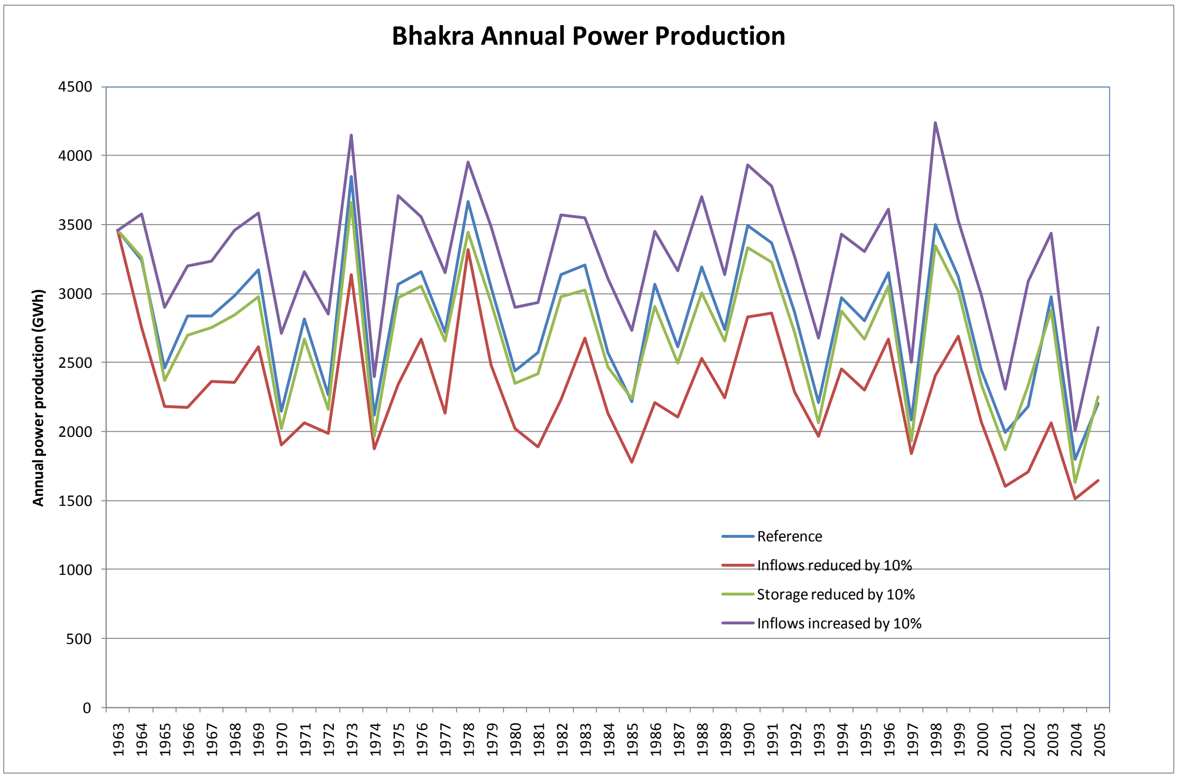


Figure 97 Simulated Bhakra Power Production



The National Water Mission (NWM) of the National Action Plan for Climate Change in 2008 produced a broad range of recommendations towards climate adaptation for the water resources and related sectors. Parts of the NWM are now being taken up; there are however major requirements for strategy and mechanisms to implement an integrated programme for climate change adaptation for water resources. Responding to this gap, the 'Support to the National Mission TA Study' has identified core actions at the central and state levels; building on the NWM recommendations as well as meeting requirements for sustainable water resources, the study has developed proposals towards a viable and workable set of initiatives and programmes for climate change adaptation.